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COLSTRIP, MONTANA - JUNE 1975

ENVIRONMENTAL RESEARCH LABORATORY

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THE BIOENVIRONMENTAL IMPACT OF A COAL-FIRED POWER PLANT

Second Interim Report

Colstrip, Montana — June 1975

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The approach employed requires (1) the use of reasonably comprehensive models of component populations of the ecosystem; (2) the use of appropriately structured field and laboratory experiments; and (3) evaluation of physiological and biochemical functions that may serve as specific indicators of air pollution stress. The study will establish one part of the cost/benefit matrix that will provide for the normalization of environmental impact information.

Included in the study are the characterization of the effects of coal-fired power plant emissions upon plant and animal community structure; primary production, invertebrate animal consumers, and decomposers; plant and animal diseases; both beneficial and harmful insects; indicators and predictors of pollution (e.g., lichens and honeybees); physiological responses of plants and vertebrate animals; insect behavior (mainly of honeybees) and production; the behavior, reproduction and development, population biology, health and condition of vertebrate animals.

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June 1975

Edited by

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U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
CORVALLIS ENVIRONMENTAL RESEARCH LABORATORY
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Supportive and integrative components include field experimental studies; mathematical modeling; remote sensing; micrometeorological investigation; chemical analyses (e.g., sulfur, fluoride) of biological specimens; and air quality monitoring that includes integrated aerosol characterization.

ACKNOWLEDGEMENTS

In addition to the authors and their respective institutions, many individuals have contributed to the development of the Colstrip, Montana Coal-fired Power Plant Project and to the preparation of this document. We would like to express our sincere appreciation to all. Personnel of the Custer National Forest and the Office of the Lieutenant Governor, State of Montana have been particularly helpful.

Our work could not proceed without the help and support of the people of Southeastern Montana, especially the ranchers on whose land we are working and the personnel and persons residing at and near Fort Howes Ranger Station. Editorial assistance was provided by Ms. Karen Manthe; the help of Ms. Patty Wilkison, Ms. Cathy Alava and others in the preparation of this document is much appreciated.

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SECTION I

INTRODUCTION TO THE COLSTRIP, MONTANA, COAL-FIRED POWER PLANT PROJECT

by

Robert A. Lewis
Allen S. Lefohn
Norman R. Glass

INTRODUCTION

The United States presently faces a series of problems concerning the production, distribution and consumption of fossil fuel energy. Because this fuel resource is abundant at relatively low cost, the Administration's desire to attain energy self-sufficiency by 1985, and other factors, it is clear that the United States is moving toward an economy based on coal as the primary fossil fuel. This rush toward energy self-sufficiency is creating new pressures on the environment. The decisions that will ultimately resolve the environmental and economic issues we face must be made with full knowledge of the constraints imposed by the need to minimize environmental impacts associated with energy production and utilization.

Currently, over 95 percent (Council on Environmental Quality, 1974) of the primary energy in the United States is produced through the combustion of fossil fuels (the remainder is derived from hydro power and nuclear energy). By the year 2000, the fossil fuel contribution to the total energy economy is expected to be approximately 70 percent, but total use of fossil fuels will probably increase by more than 100 percent. During the same period, nuclear energy production is expected to grow ten-fold.

There is a clear relationship between research conducted on energy-related problems and research which has been carried out to set or revise air and water quality standards that are designed to maintain environmental quality. This is due to the fact that environmental research designed to determine the effects on biota and ecological processes is concerned with the same types of pollutants or residuals for standard setting purposes as for identifying the effects of energy extraction, conversion, or generation. For example, ambient air quality standards have been established under the Clean Air Act Amendments of 1970 for the major, but not all, pollutants generated by fossil fuels. National Ambient Air Quality Standards (NAAQS) have been established for sulfur oxides (SO_x), particulates, carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons, and oxidants. These standards were based upon the best information available at the time of their promulgation. New source performance standards (NSPS) have been established for several industries, including electric utilities. These new standards restrict the emissions of SO_x, NO_x, particulates, and other pollutants and apply to the operation of fossil fueled generating plants constructed or modified after August 1971.

In general, progress is being made toward attaining higher ambient air quality levels nationwide. However, certain air quality control regions may not meet statutory deadlines for reaching suitable air quality levels. Considering all 247 air quality control regions of the country, it is anticipated that 60 will not meet the statutory deadlines for particulates (TSP), and 42 will not meet the deadline for sulfur dioxide (SO_2). About the same number of air quality control regions will not meet the deadline for oxidants, NO_x, and CO. For areas with high ambient SO_2 levels generally, the cause is emissions from an uncontrolled point source such as a smelter or power plant. While most air quality control regions can anticipate that rigorous enforcement of existing regulations will be adequate to meet SO_2 standards, future problems may arise because of inadequate supplies of low sulfur fuel or installations and application of flue gas desulfurization equipment.

The Clean Air Act states that "...air quality criteria for an air pollutant shall accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of such pollutants in the ambient air, in varying quantities" [section 108(a)]. The Act further states that national primary ambient air quality standards are regulations which "...in the judgment of the administrator, based on such criteria, and allowing for an adequate margin of safety, are requisite to protect the public health" [section 109(b)]. Air quality criteria, then reflect scientific knowledge, while primary air quality standards involve a judgement as to how this knowledge must be used in a regulatory action to protect public health. The secondary air quality standards determine the level of air quality required to protect the public welfare. Public welfare as defined in the Clean Air Act "...includes, but is not limited to, effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate...[section 302(h)]."

These considerations also apply and become focal points for energy related environmental research. It is clear that the research experience gained in meeting requirements of the Clean Air Act is valuable in pursuing energy related research. In fact, the objectives of each set of research programs are so similar that precise separation is not possible.

The major categories of air pollutants emanating from fossil fuel energy systems are sulfur oxides, nitrogen oxides and particulate matter. Energy systems also contribute, to a lesser degree, to carbon monoxide and oxidant burdens. Primary ambient air standards, based on health effects have been established for these pollutants. Secondary standards have been established for sulfur dioxide, particulates, carbon monoxide, oxidants, hydrocarbons, and nitrogen dioxide. These standards were based on the best scientific information available at the time of their creation. However, when they were established, significant knowledge gaps existed; even now major gaps in knowledge still exist for each pollutant. Therefore, under the Clean Air Act, EPA is required to continually examine and update the criteria for these standards. In addition to the above pollutants, numerous trace metals (such as copper, cadmium, zinc, lead, arsenic, mercury, and others), are emitted from fossil-fueled power generating plants. Numerous other trace contaminants in the form of hydrocarbons and various aerosols are also emitted from power plants. In general, trace metals are emitted as particles adsorbed to fly ash and/or other particulate matter coming from the stack of the coal-fired power plant.

The following discussion represents an overview of the National Ecological Research Laboratory's recently initiated coal-fired power plant project. The broad objective of this program is to develop a set of guidelines which planners can use in predicting the impact of power plants on a grassland ecosystem. This study is concerned not only with the stability of ecosystem organization in relation to ambient conditions, but also with the predictability and reproducability of changes that do occur. Insight into the mechanisms of dynamic-structural responses of ecosystem components to air pollution challenge is also sought. Identification of subsystem functions that contribute to ecosystem regulation and the mechanisms whereby such regulation is effected is of special concern.

This investigation represents an effort to characterize the impact of air pollutants on a total ecosystem. It is the first attempt to generate methods that can predict bioenvironmental effects of air pollution before damage is sustained. Historically, most terrestrial air pollution field research has dealt almost exclusively with direct, usually acute, effects on vegetation. We expect to observe complex changes in ecosystem dynamics as a function of relatively long term, chronic pollution challenge.

By studying a rather broad range of interacting variables, we hope to isolate some of these as sensitive and reliable measures of air pollution impact.

The approach employed requires (1) the use of reasonably comprehensive models of component populations of ecosystems; (2) the use of appropriately structured field and laboratory experiments; and (3) an evaluation of physiological and biochemical functions that may serve as specific indicators or predictors of air pollution stress.

Even in a comprehensive investigation, extensive studies of a large array of species or processes is not possible. Considerable research is required to identify the specific parameters that will give an adequate, sensitive measure of air pollution to a grassland ecosystem and/or its components. Broad categories of important functions under investigation include (1) productivity or biomass of ecosystem compartments; (2) life-cycle and population dynamic functions of "key" taxa; (3) community structure or diversity; (4) nutrient cycling; (5) sublethal biochemical or physiological changes in individuals or compartments; (6) behavior of mobile organisms; and (7) reproductive patterns and breeding success of terrestrial vertebrates.

If we are to assess and interpret the effects of air quality upon natural ecosystems, it is essential to understand the wide range of abiotic factors (e.g., weather, geography, insolation, hydrology, etc.) that influence the dynamics of the living components of the ecosystem. Optimum production, the maintenance of stability and diversity, and other desirable properties of ecosystems all depend upon a variety of these abiotic factors. Thus, appropriate micrometeorological and air quality support is provided to this study.

RATIONALE

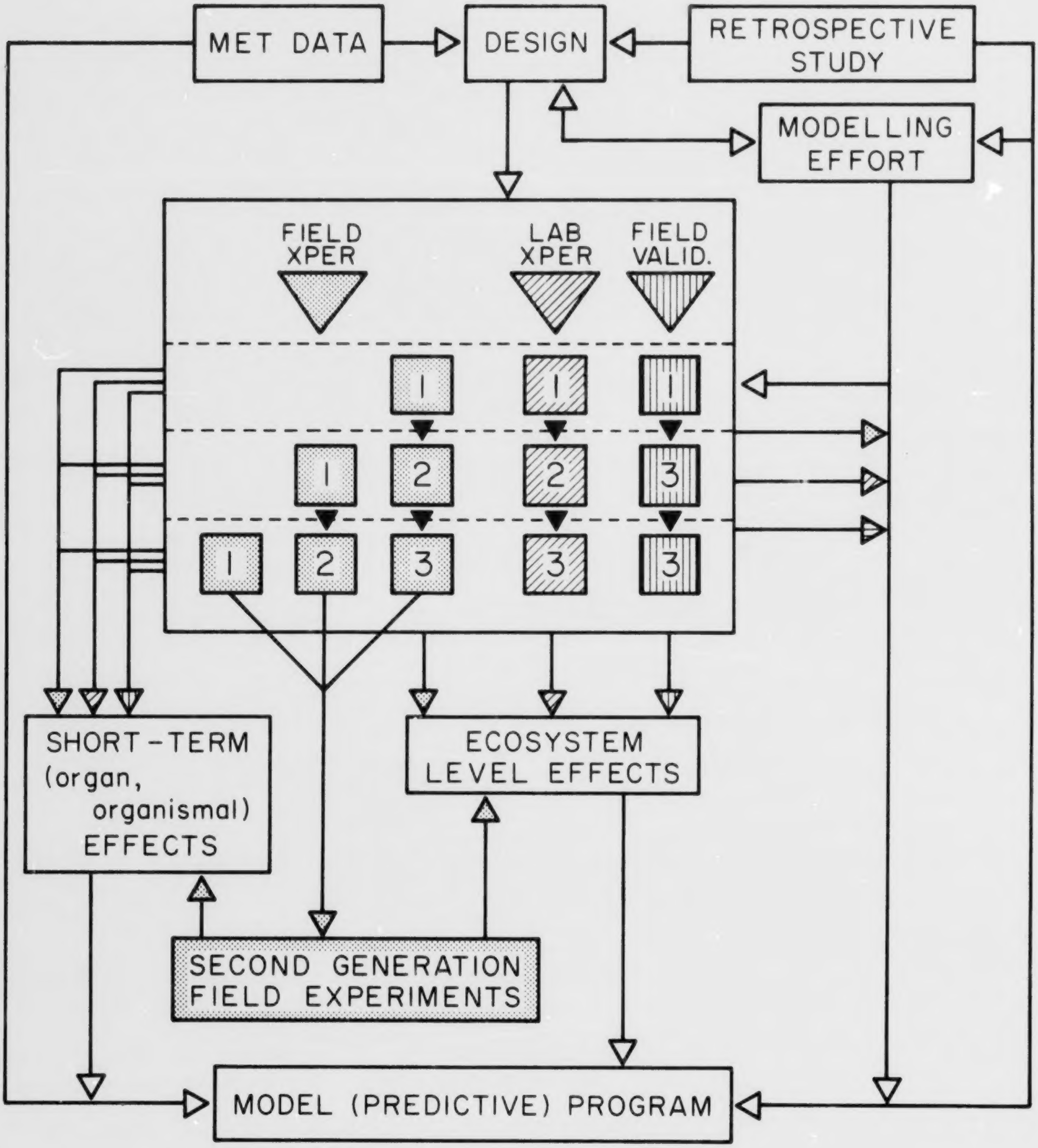
In addition to the "simple" direct effects of air pollutants that have been reported from experimental studies of natural systems, we may expect to observe complex changes in ecosystem dynamics as a function of pollution challenge. We know that insults to the environment from rather diverse sources (toxic substances, pesticides, radiation, disease, and adverse climate) produce a similar array of effects at the community level in spite of very different effects on individual organisms studied under experimental conditions. The response mechanisms may vary, but results are often similar: (1) a "reversal" of succession or simplification of ecosystem structure; (2) a reduction in the ratio of photosynthesis to respiration; and (3) a reduction in species diversity at more than one trophic level, which may include the elimination of certain species (e.g., in grassland, usually rare, but characteristic species). Effects may be temporary and reversible (i.e., the system adapts) or chronic and cumulative. In any case, if a coal-fired power plant has a measurable impact on the environment, there is every reason to believe that it will be registered as an alteration of community structure.

Both plant and animal diversity and energy transfer between and within trophic levels are measures of community structure. Also, these functions may be regarded as important ecosystem resources. We hypothesize that the immediate population-level effects from environmental stress may result from differential impairment of competitive ability. At the relatively low pollution levels anticipated in the investigation, we may expect to find predisposing and subclinical effects that will be impossible to detect in the absence of appropriate population dynamic, biochemical and physiologic information.

Effects need not be mediated by alterations in food chains or energy flow. Certainly food chains and mass and energy flow patterns will be affected (although possibly secondarily) whenever population adjustments occur. For example, a pollutant may alter the physiology or behavior of the individuals that comprise a population. These alterations are ultimately reflected in altered survival, reproduction and/or emigration rates. Such effects may be subtle and difficult to relate to the specific stressor. In the real world, numerous stressors are operating in complex ways with various lag times; these tend to confound the results of any field evaluation of a single stressor. The end result of the community response to a continued environmental stress is a readjustment of the component populations (plant and animal) at a new state of dynamic equilibrium. It is not possible to predict with any confidence either the adjustments and mechanisms most critically involved or the final population levels that will be reached. By studying a rather broad range of interacting variables and, in particular, by an intensive study of certain populations, some may be isolated as sensitive and reliable measures of air pollution. Table I-1 outlines the existing research plan.

Figure I-1 summarizes the operational plan of the project. The four major components (field and laboratory experiments, field validation, and modeling) form an integrated approach; information generated by each component is used to guide the course of the other components. The goal is to generate information on both short-term and longer-term responses and, with appropriate models, to integrate and relate these data to generate procedures for impact assessment that are truly predictive. The recruitment of a new field experimental system each year for three years will allow us to evaluate both within-year and between-year sources of variance. This temporal structure of the field experimental system will further allow us to conduct new experiments during the third year of the study to test hypotheses generated by our field experience and modeling efforts during the first two years of the study.

Figure I-1 Operational Plan and Flow Diagram. Numbers represent the project year. See accompanying text.


MET DATA
DESIGN
RETROSPECTIVE STUDY
MODELLING EFFORT
FIELD XPER
LAB XPER
FIELD VALID.
1
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3
SHORT-TERM (organ, organismal) EFFECTS
ECOSYSTEM LEVEL EFFECTS
SECOND GENERATION FIELD EXPERIMENTS
MODEL (PREDICTIVE) PROGRAM

Table I-1. OUTLINE OF THE RESEARCH PLANT FOR THE MONTANA COAL-FIRED POWER PLANT PROJECT

I. Field Investigation

- A. Temporal and spatial quantitative inventory of components of the study area, with particular focus on the annual cycle phenomena of key species.
- B. Meteorological measurements to support the modeling and experimental air pollution research efforts.
- C. Development of remote sensing as a tool for detecting effects of air pollutant challenge on the ecosystem.
- D. Measurement of loss of inventory attributed to strip mining, power lines, human activity, water use, and other potentially confounding influences, e.g., pesticides, disease, population cycling.

II. Air Pollution Experiments

- A. Experimentally controlled air pollution of spatial segments of an ecosystem.
- B. Detailed measurement of biological structure and function, including energy flow, nutrient cycling and species condition, composition and diversity during and following air pollution stress.

III. Laboratory Experiments

- A. Measurement and evaluation of physiologic, biochemical and behavioral mechanisms of response to air pollution challenge.
- B. Precise measurement of parameters that support dynamic models.
- C. Experiments designed to test whether changes observed in experimental study plots can be attributed to air pollutant stress.
- D. Secondary stresser experiments (e.g., disease, temperature stress, water stress, non-specific stress).
- E. Experiments designed to test field-generated hypotheses.

IV. Modeling

- A. Use of an ecosystem level model to describe and predict effects of air pollutant challenge.
- B. Use of models to help design experiments.
- C. Use of models to help disentangle pollutant effects from natural variation and system dynamics.
- D. Meteorological and dispersion modeling to describe the mode of entry of pollutant into the ecosystem and its time and space distribution and concentration.

BASIS FOR SITING THE INVESTIGATION IN SOUTHEASTERN MONTANA

The identification and selection of an appropriate study area was essential to structuring the entire investigation. Colstrip was selected on the basis of our initial literature review and several field trips to Montana and Wyoming. The principal criteria used to select the study area are detailed below:

1. The region is climatically and ecologically representative of a relatively large portion of the North Central Great Plains.

2. The Colstrip area of the Fort Union Basin is a relatively pristine pine savanna area which has never been subjected to [toxic] gaseous or particulate emissions from a stationary source. Thus the vegetation and non-migratory animals in the area, although stressed by various environmental factors such as drought, adverse temperatures, nutrient deficiencies, etc., have never experienced the added stress of air pollutants. Previous air pollution studies around power plants (e.g., the Environmental Protection Agency's Mount Storm studies; the Tennessee Valley Authority's pre- and post-operational studies; Large Power Plant Effluent Study (LAPPES) [APTD 70-2, 0589, and 0735] and others([EPA 660/3-74-011]) have generally occurred after the power plants are on line, or in areas that have suffered substantial pollution prior to operation of the power plant. Thus, it has been impossible to assess adequately the first introduction of toxic power plant emissions into plants to an essentially pristine ecosystem.

3. Montana laws favor rational resource development.

4. Current assessments indicate that Montana contains nearly a third of the strippable coal reserves in the North Central Great Plains. It is possible that some 120,000 acres will be stripped during the next two decades.

5. Southeastern Montana is a rich rangeland resource.

6. Existing data, although scarce, indicate that air quality in Eastern Montana is well above the national average.

7. Local-regional emission sources (see Regional Profile Report on Atmospheric Aspects, Northern Great Plains Resource Program, April 1974 [draft copy]) other than the coal-fired power plant at Colstrip are unlikely to contribute significantly to the air pollution burden of the Rosebud Creek Watershed during the period of investigation.

8. The projected sites and schedules of strip-mining and power plant development are known.

9. The history of human disturbance is reasonably well-documented.

10. We expect human disturbance (except that associated with coal mining and coal-conversion) to be relatively minimal throughout the investigation period. We feel reasonably assured that sample sites, including buffer zones and reference sites, will remain substantially free of confounding disturbance.

11. Other investigations underway at Colstrip complement this investigation; thus, this research will broaden and extend an existing data base.

SCOPE AND PURPOSE

Following one year of intensive preparation, the overall investigation is planned as a three-year field effort. A fourth year will be allowed for data analyses and evaluation. Most of the field activities during each sampling year will occur from April through October, although some components will continue throughout the entire annual cycle. We expect the evaluation and synthesis of our results to generate a protocol that will permit planners to assess the impact of energy conversion activities on grasslands in the Northern Great Plains prior to the initiation of site selection activities. Achievement of this objective would favor valid siting and regulatory decisions. Full realization of this objective within the projected time frame will require a synthesis of the National Ecological Research Laboratory's effects research data and coordination with the results of socio-economic and transport/fate research projects. This will be difficult to accomplish, but the rewards are potentially great.

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SECTION II

MONITORING PLANT COMMUNITY CHANGES DUE TO EMISSIONS FROM FOSSIL FUEL POWER PLANTS IN EASTERN MONTANA

by

J. E. Taylor, W. C. Leininger, and R. J. Fuchs

This component of the Montana Coal-Fired Power Plant Project was initiated on 15 July 1974.

Specific tasks are to:

1. Document pre-treatment native plant communities in areas likely to be affected by the power plants under investigation and on areas to be stressed artificially with pollutants.
2. Develop measurement techniques and monitor changes in plant community structure, diversity, phenology, and speciation following air pollution stress.
3. Develop detailed vegetation maps of the study areas.
4. Provide data for simulation models to predict bioenvironmental changes resulting from fossil fuel power generation in other areas.

Due to the late starting date some objectives were not realized the first summer. When the field work was initiated, many of the ephemeral plants were dry and were either impossible to identify or absent from the sites. The late date also hampered the color infrared photography work and seed and plant collections. The main first year accomplishment was the development of specialized techniques.

The 1974 work concentrated on the project's experimental areas, including the proposed stressing site at Ash Creek (where grassland was to be artifically fumigated) and the validation sites near Colstrip.

Additional Colstrip sites were located on three adjacent, relatively undisturbed knolls, referred to as relict knolls A, B, and C (Figure II-1).

Project activities to date may be classified into these categories:

Description and Characterization of Study Areas

Analysis of Plant Community Structure

Photographic Monitoring

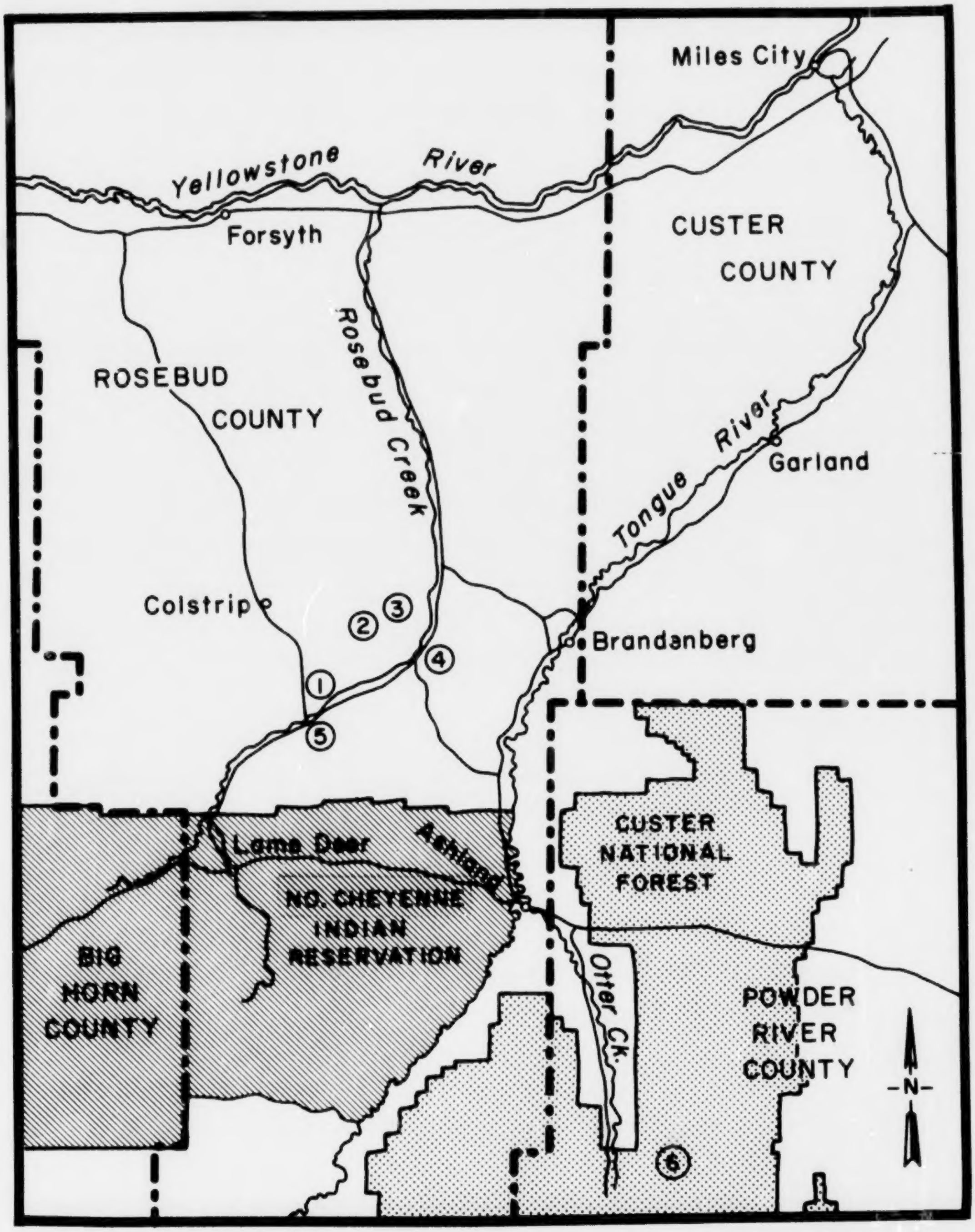
Description and Characterization of Study Areas

Each study site was described in detail (Taylor, Leininger, and Fuchs, 1975). Data were recorded on exact location, topography, soils, and vegetational composition (Table II-1).

The Zonal Air Pollution System operation has been moved from Ash Creek to Taylor Creek (Lee, Lewis and Body, 1975) (Figure II-2). This new site is about 7.5 miles (12 km) SSE of the Ash Creek site in Fort Howes District of the Custer National Forest.

The Taylor Creek site lies about 54 miles (86 km) southeast of Ashland in W 1/2 S9 T7S R47E, MPM. The exclosure lies on a 6 to 8

Figure II-1 Locations of Principal Study Sites (1=Hay Coulee, 2=Cow Creek, 3=North Pasture, 4=School Section, 5=Relict Knolls, 6=Ash Creek).


Miles City
Yellowstone River
Forsyth
CUSTER COUNTY
Rosebud Creek
ROSEBUD COUNTY
Tongue River
Garland
Colstrip
②
③
①
④
⑤
Brandanberg
Lame Deer
Ashland
NO. CHEYENNE INDIAN RESERVATION
BIG HORN COUNTY
CUSTER NATIONAL FOREST
Otter Ck.
POWDER RIVER COUNTY
⑥
-N-

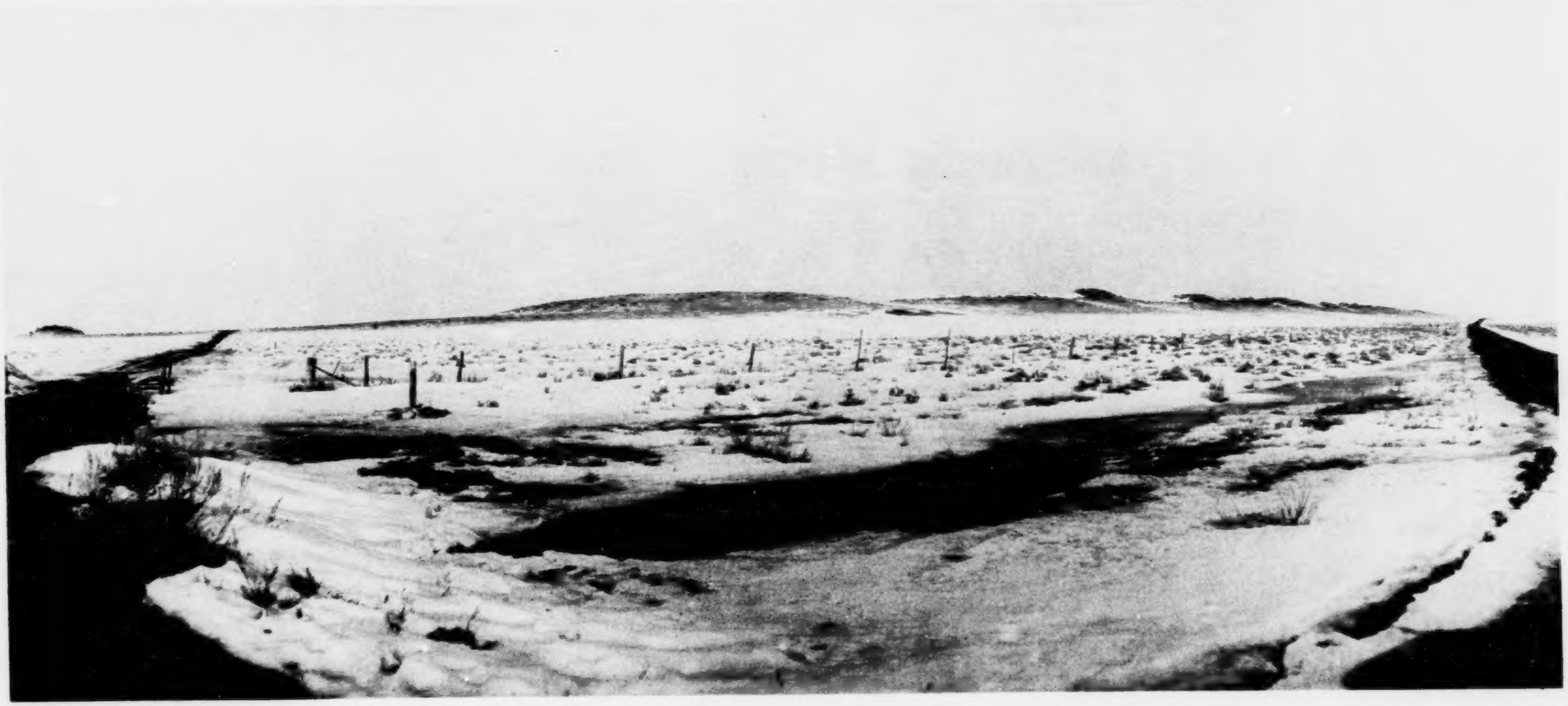


Figure II-2 Panoramic View of Taylor Creek Site, 17 March 1975.

Table II-1. CHARACTERIZATION OF STUDY SITES

Name	Distance (km) & Direction fr/ Colstrip	Elevation (meters)	Slope & Exposure	Plant Aspect[1/]	Soil Characterization
Ash Creek	74.8 SE	1173	4-5% NE	AGSM, KOCR, BRJA	Residual silt loam
Hay Coulee	11.6 SE	927	4% NNE	AGSM, ARTR, KOCR, BRJA	Colluvial clay loams
Cow Creek	11.6 ESE	917	6% N	STCO, AGSM, BRJA, BRTE	Colluvial sandy loams
North Pasture	14.7 E	902	5% NE	STCO, ARFR, AGSM, BRJA	Colluvial sandy loams
School Section	18.3 ESE	904	3 1/2% NE	AGSM, BRTE, BRJA, ARFR	Residual and colluvial clay loams
Pristine Knolls A	13.8 SE	908	2% ESE	CALO, SCSC, AGSP	Colluvial and residual sandy loams
B		902	4 1/2% NW	AGSP, STCO, ARTR	Colluvial and residual loams
C		908	6 1/2% SE	STCO, CAFI, AGSM	Colluvial and residual sandy loams

[1/] AGSM = Western wheatgrass (*Agropyron smithii*)
ARCA = Silver sage (*Artemisia cana*)
BRJA = Japanese brome (*Bromus japonicus*)
ARTR = Big sagebrush (*Artemisia tridentata*)
AGSP = Bluebunch wheatgrass (*Agropyron spicatum*)
CAFI = Threadleaf sedge (*Carex filifolia*)
KOCR = Junegrass (*Koeleria cristata*)
STCO = Needle-and-thread (*Stipa comata*)
BRTE = Cheatgrass (*Bromus tectorum*)
ARFR = Fringed sagewort (*Artemisia frigida*)
SCSC = Little bluestem (*Schizachyrium scoparium*)
CALO = Prairie sandreed (*Calamovilfa longifolia*)

percent southwest facing slope, and the elevation is about 1220 meters. Soils are loams, derived from colluvium and parent materials weathered in place. The site is considered in good range condition; dominant vegetation is western wheatgrass (*Agropyron smithii*), Sandberg bluegrass (*Poa secunda*), and junegrass (*Koeleria cristata*). Major plant associates are needle-and-thread grass (*Stipa comata*), common dandelion (*Taraxacum officinale*), and western yarrow (*Achillea lanulosa*).

Further sites have been examined for possible future use, including areas east of Colstrip and several sites on the Ashland Division, Custer National Forest.

Plant Community Structure

Canopy cover estimates were made on all intensively-studied locations and on all three relict knolls. The technique used was that of Daubenmire (1959), i.e., a 2 X 5 dm plot frame in which each species canopy cover is classified into one of six categories. At each site, 50 frames were examined on each sampling date.

Diversity Studies. Numerical data for index of diversity studies (species and individuals per species) were recorded for each Daubenmire plot concurrently with canopy cover. Diversity indices used were:

1. Shannon-Weaver Function

$$H' = \sum_{i=1}^{S} Pi \log Pi$$

Where H' = the index of diversity

S = the number of species present

Pi = the number of individuals per species divided by the total number of individuals sampled.

H' is an estimation of Brillouin's H, the true population diversity. At large sample sizes the value for H' is almost exactly that for H. In addition, since log Pi is used, rarer species aren't discriminated against (Pielou, 1966; Shannon and Weaver, 1963).

2. Simpson's D

$$D = 1 - \sum_{i=1}^{S} Pi^2$$

Where D = the index of diversity

S = the number of species present

Pi = the number of individuals per species divided by the total number of individuals sampled.

While values for D agree closely with values for H', the expression Pi^2 used in the formula discriminates against the rarer species (Simpson, 1949).

3. Redundancy

$$R = (H'max-H')(H'max-H'min)$$

Where R = redundancy

H' = Shannon's H'

H'max+H'min are the maximum and minimum possible values, respectively, for H' based on the species and total number of individuals recorded.

Redundancy is a measure of evenness or equitability which relates the observed H' to the maximum and minimum possible values of H' given the number of species and total number of individuals present (Hamilton, 1974).

4. Probability of Interspecific Encounter (P.I.E.)

$$\Delta_1 = \left[\frac{N}{N-1}\right] \quad 1-\sum_{i=1}^{S} Pi^2 = \left(\frac{N}{N-1}\right)D$$

Where Δ_1 = the probability of interspecific encounter (P.I.E.)

D = Simpson's D
N = the total number of individuals sampled.

P.I.E. is an index of diversity based on Simpson's D. It is the probability an individual has of encountering an individual of another species (Hurlbert, 1971).

5. Probability of Intraspecific Encounter (Pa)

$$Pa = 1 - \Delta_1$$

Where Pa = the probability of intraspecific encounters

Δ_1 = P.I.E.

Pa is the complement to P.I.E. (Hurlburt, 1971). It measures the probability an individual has of encountering another individual of the same species in the population sampled.

6. P.I.E. Transformation (Δ_3)

$$\Delta_3 = 1/ \sum_{i=1}^{S} Pi^2$$

Where Δ_3 = P.I.E. transformation

$\sum_{i=1}^{S} Pi^2$ = the expression from Simpson's D.

The P.I.E. transformation is used to increase the spread between values for Simpson's D at the upper portion of its range (Hurlbert, 1971).

7. Fisher's α

$$\alpha = \frac{N(1-X)}{X}; \; N = \frac{n,}{1-X}$$

Where α = the index of diversity
N = the total number of individuals sampled
n, = number of species with just one individual.

Fisher's α is based on the number of species in the sample containing only one individual (Fisher, Corbett, and Williams, 1943).

Table II-2. COMPARISON OF VARIOUS INDICES OF DIVERSITY, BASED ON PLANT NUMBERS

Site	Fisher's α	Simpson's D	H'	Redundancy	P.I.E.	Pa	Δ_3
North Pasture	3.0382	.8765	1.0506	.2808	.8768	.1232	8.0972
Hay Coulee	5.0052	.8585	.9804	.3275	.8587	.1413	7.0671
Cow Creek	5.0053	.8433	.9464	.3516	.8435	.1565	6.3816
Ash Creek	2.0010	.8423	1.0590	.3547	.8425	.1575	6.3412
School Section	6.0112	.8194	.8886	.3948	.8196	.1804	5.5371

Table II-3. SPEARMAN RANK CORRELATION COEFFICIENTS, BASED ON PLANT NUMBERS

	D	H'	R	P.I.E.	Pa	$\Delta 3$
D	-	0.4	-1.0	1.0	-1.0	1.0
H'	0.4	-	-0.4	0.4	-0.4	0.4
R	-0.1	-0.4	-	-1.0	1.0	-1.0
P.I.E.	1.0	0.4	-1.0	-	-1.0	1.0
Pa	-1.0	-0.4	1.0	-1.0	-	-1.0
Δ_3	1.0	0.4	-1.0	1.0	-1.0	-

Table II-4. PEARSON'S PRODUCT OF MOMENTS CORRELATION COEFFICIENTS, BASED ON PLANT NUMBERS

	D	H'	R	P.I.E.	Pa	Δ3
D	-	0.4	-1.0	1.0	-1.0	1.0
H'	0.4	-	-0.4	0.4	-0.4	0.4
R	-1.0	-0.4	-	-1.0	1.0	-1.0
P.I.E.	1.0	0.4	-1.0	-	-1.0	1.0
Pa	-1.0	-0.4	1.0	-1.0	-	-1.0
Δ_3	1.0	0.4	-1.0	1.0	-1.0	-

Table II-5. F RATIOS (BASED ON VARIANCES) COMPARING THE FIRST VS. SECOND SAMPLING PERIODS FOR EACH INDEX FOR EACH SITE

Site	Shannon-Weaver Function	Simpson's D	Redundancy
Hay Coulee	1.70*	3.19***	1.23
Pasture North	2.12**	5.47***	1.24
Cow Creek	1.73*	2.10**	2.13**
School Section	1.53	2.64***	2.06**

*   = significant at the .05 confidence level
** = significant at the .01 confidence level
*** = significant at the .001 confidence level

Table II-6. TEST OF EQUALITY OF MEANS OF TWO SAMPLES, VARIANCES UNEQUAL (A COMPARISON OF THE FIRST VS. SECOND SAMPLING PERIOD MEANS OF EACH INDEX FOR EACH SITE)

Site	Shannon-Weaver Function	Simpson's D	Redundancy
Hay Coulee	7.82***	6.84***	0.41
North Pasture	4.31***	3.02**	0.63
Cow Creek	7.26***	4.12***	0.49
School Section	6.70***	5.80***	2.50*

*   = significant at the 0.5 confidence level
** = significant at the .01 confidence level
*** = significant at the .001 confidence level

A comparison of the various indices is given in Table II-2. Statistical tests of correlation appear in Tables II-3 and II-4. Note that all indices were calculated on a site-by-site, not frame-by-frame basis. Standard errors are thus not presented.

The various indices correlate quite closely except for Fisher's α (Tables II-2, II-3, and II-4). The high value for H' for the Ash Creek site is probably due to a greater number of forbs, reflecting a more favorable plant habitat.

Using the random line placement technique, additional statistical tests were performed on data from the primary sites during the first and second sampling periods.

Tests were run on each of three primary indices of diversity: the Shannon-Weaver function (HP), Simpson's D (D2), and redundancy (BR) (Tables II-5 and II-6).

Bartlett's test for homogeneity of variances gave a χ^2 value of 23.76 for HP, 65.14 for D2, and 14.44 for BR. The first two are significant at the .001 confidence level; the third is significant at .05. These results permitted testing for equality of means with heterogeneous variances. Results produced F_s values of 44.98 for HP, 3770.01 for D2, and 1.73 for BR. The first two were significant at the .001 confidence level while BR was not significant. Significant differences show that the samples were taken from populations with unequal means.

Table II-5 presents results of an F test based on variances. Again, significant differences demonstrate that the samples were drawn from populations with unequal means. These results allow use of a test for equality of means of two samples with unequal variances (Table II-6).

The results thus far have been highly encouraging, especially those documented in Table II-6 which compare the means of the first and second sampling period for each site. Both the Shannon-Weaver function and Simpson's D yield significant differences at the .01 to .001 confidence levels. This demonstrates that these indices can record changes in a natural rangeland ecosystem as the growing season progresses. Since these changes may be viewed, in part, as the ecosystem's response to climatic stress, we may infer that the tests also are sensitive enough to monitor changes created by pollution or other types of stress on a rangeland ecosystem.

Redundancy has not yielded comparable results. Dr. Martin Hamilton, biostatistician in the Mathematics Department, Montana State University, is devising a redundancy index based on Simpson's D rather than on the Shannon-Weaver function. He is also developing statistical tests of significance that should be specifically applicable to indices of diversity. Thus, project staff will not be dependent on generalized tests of significance. These techniques will be tested and applied to the 1975 data.

Site Similarity Comparisons. Frequency data from all sites were used to construct a similarity matrix, using the relationship $I = \frac{2W}{a+b}$, where I = Index of Similarity, W = the sum of frequency in common between two stands (sites), a = the sum of frequencies of the first stand and b = the sum of frequencies of the second stand (Sorenson, 1948).

The similarity matrix was the basis for a two-dimensional ordination (Bray and Curtis, 1957) and a cluster dendrogram (Sorenson, 1948). The ordination (Figure II-3) and the dendrogram (Figure II-4) show a reasonably high degree of similarity among all sites. The sites fall into three major groupings: Ash Creek and Hay Coulee; Cow Creek, North Pasture, and School Section; and the three relict knolls. The overall I-value of

Figure II-3 Ordination of Intensive Sites, Based on Indices of Similarity (frequency). 1=Hay Coulee; 2=Cow Creek; 3=North Pasture; 4=School Section; 5=Relict Knolls; 6=Ash Creek

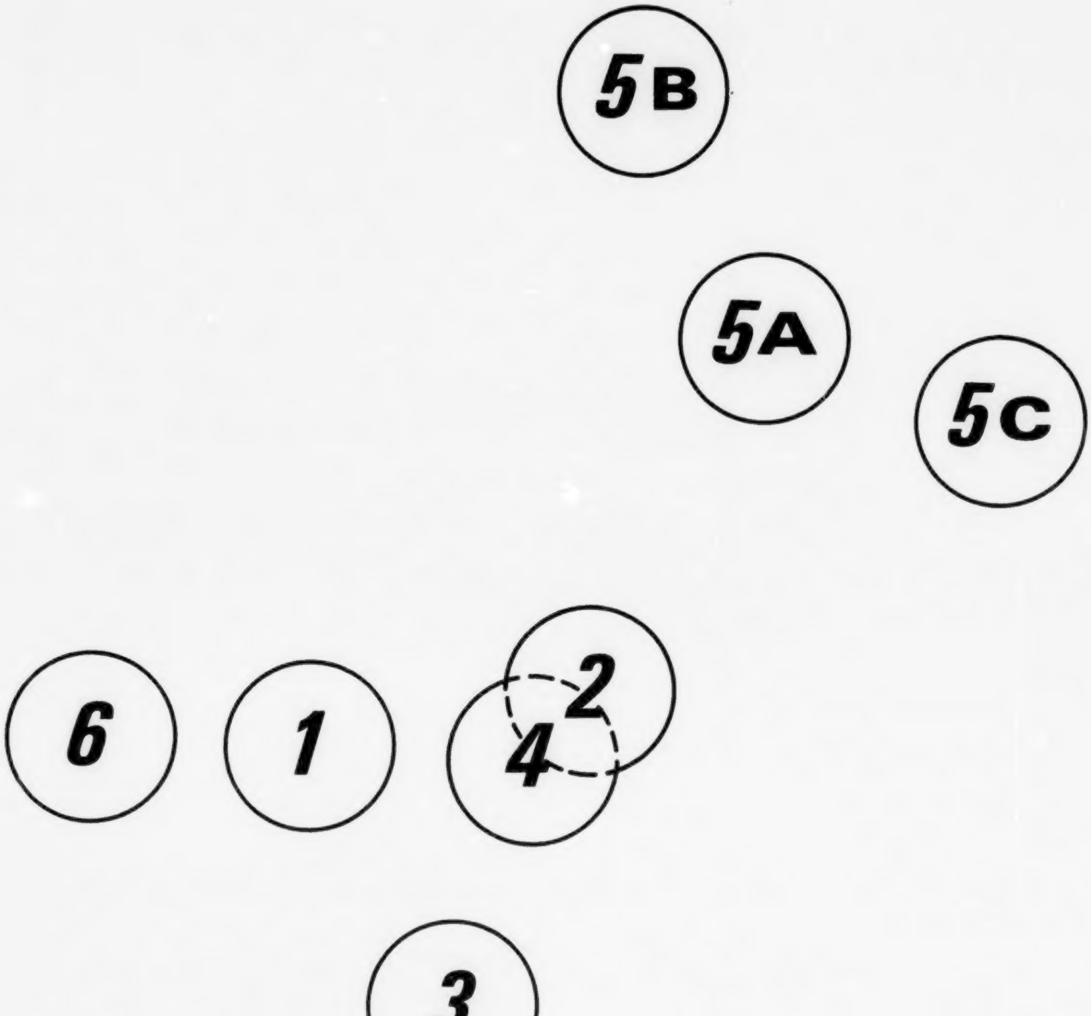
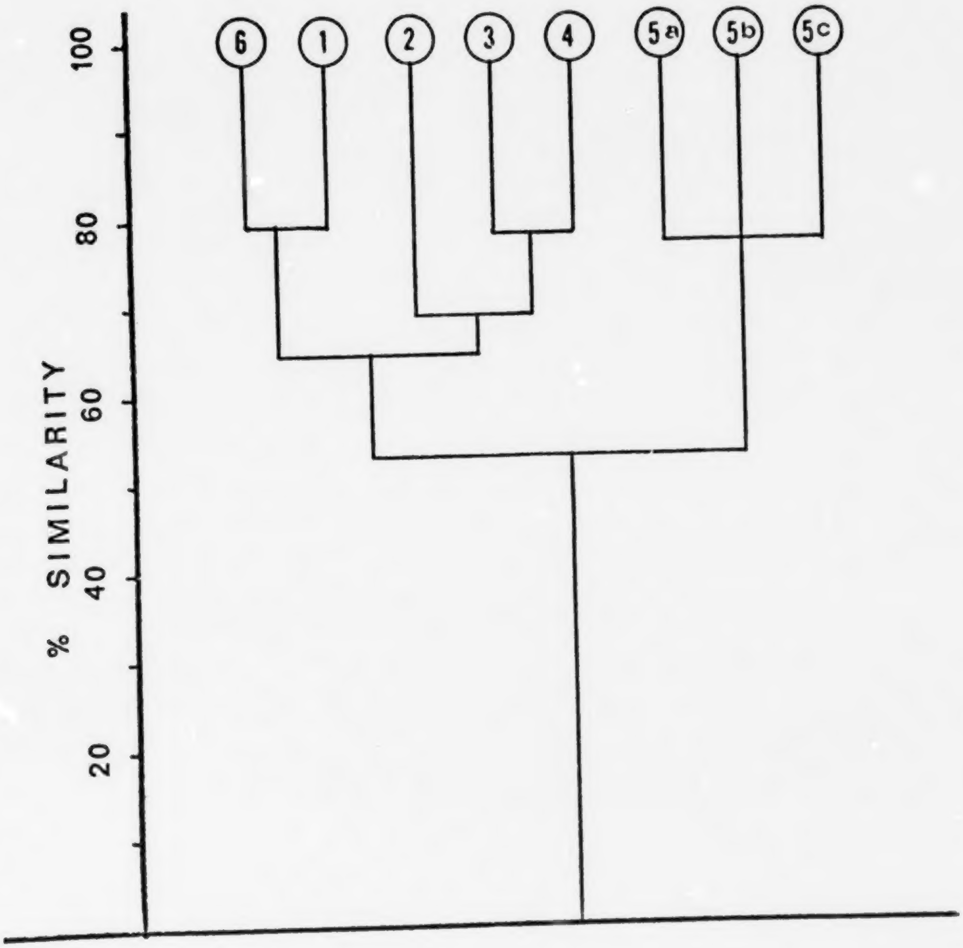


Figure II-4 Cluster Dendrogram of Intensive Sites. See Figure II-3 for definition of symbols.



52.5 indicates a reasonable level of comparability among the study sites.

Phenology. Initial observations were made to test a phenological scorecard developed for this project. The lateness of the season precluded the development of an annual phenologic profile for the study areas, but this system should be useful in subsequent seasons. The phenological stages recognized are shown in Table II-7.

Considerable interest has been shown among grassland researchers in the project's plant phenology techniques. Because of this, we have reviewed the literature on the design and use of phenology indices, and are preparing a manuscript on the subject. We have provided copies of the phenology scale to several correspondents.

Plant Collection. The field crew collected all plant species on each study site as they came into flower. This year only late flowering species were obtained. Future collections will include specimens of the early flora. This material will provide a reference herbarium for local consultation. Specimens also will be submitted to the Montana State University Herbarium for taxonomic verification and voucher purposes.

Seed Collection. Seeds of common plant species were collected. This material will be used by the vertebrate animal research personnel in examining food habits of the populations under study. This work will continue in future years.

Photographic Monitoring

Permanent Ground Photo Plots. Initial photo plots were established and photographed at all locations. At Ash Creek, two plots were placed in each of the proposed stress sites. At Hay Coulee, Cow Creek, North

Table II-7 Phenology Code

Code	Stages
1	Cotyledon (newly germinated)
2	Seedling
3	Basal Rosette
4	Early greenup, veg. buds swelling
5	Vegetative growth, twig elongation
6	Boot stage, flower buds appearing
7	Shooting seed stalk, floral buds opening
8	Flowering, anthesis
9	Late flowering
10	Fruit formed
11	Seed shatter, dehiscence
12	Vegetative maturity, summer dormancy, leaf drop
13	Fall greenup
14	Winter dormancy
15	Dead

Pasture, and School Section, two photo plots were established in each exclosure; one photo plot was placed on each of the three relict knolls.

The photo plots were 3x3 feet and marked for relocation. Each was photographed in color from a high oblique angle (25° from vertical). Stereoscopic photography was used to facilitate plant identification. Most plots were also photographed with infrared color film. After the oblique photographs were made, the camera was tilted up so that the field of view included the horizon, and an aspect picture was taken. At the same time that the plot photography occurred, a rough chart was prepared to show locations and identifications of the various species. This will help in the photograph interpretative work. An example stereogram is shown in Figure II-5.

Enlargements (8"x10") of permanent plot photographs are being interpreted by preparing species overlays. These will constitute baseline maps of the monitoring stations, and will be used to follow changes in species composition and cover.

Using a computer plotting procedure, some of the photographs are being charted in three dimensions. Researchers will evaluate the effectiveness of this technique in plant monitoring activities.

Procedures for ground level photo plots will be changed for this field season. Instead of the oblique photographs made in 1974, vertical stereoscopic photo pairs will be taken of all permanent photo plots. These will be replicated with color, infrared color, and black-and-white. This should permit equally good photographic interpretation of the plant communities being sampled and allow quantification of vegetation parameters such as density, number, cover, and individual plant location. The stereoscopic coverage will enable the researchers to make volume and

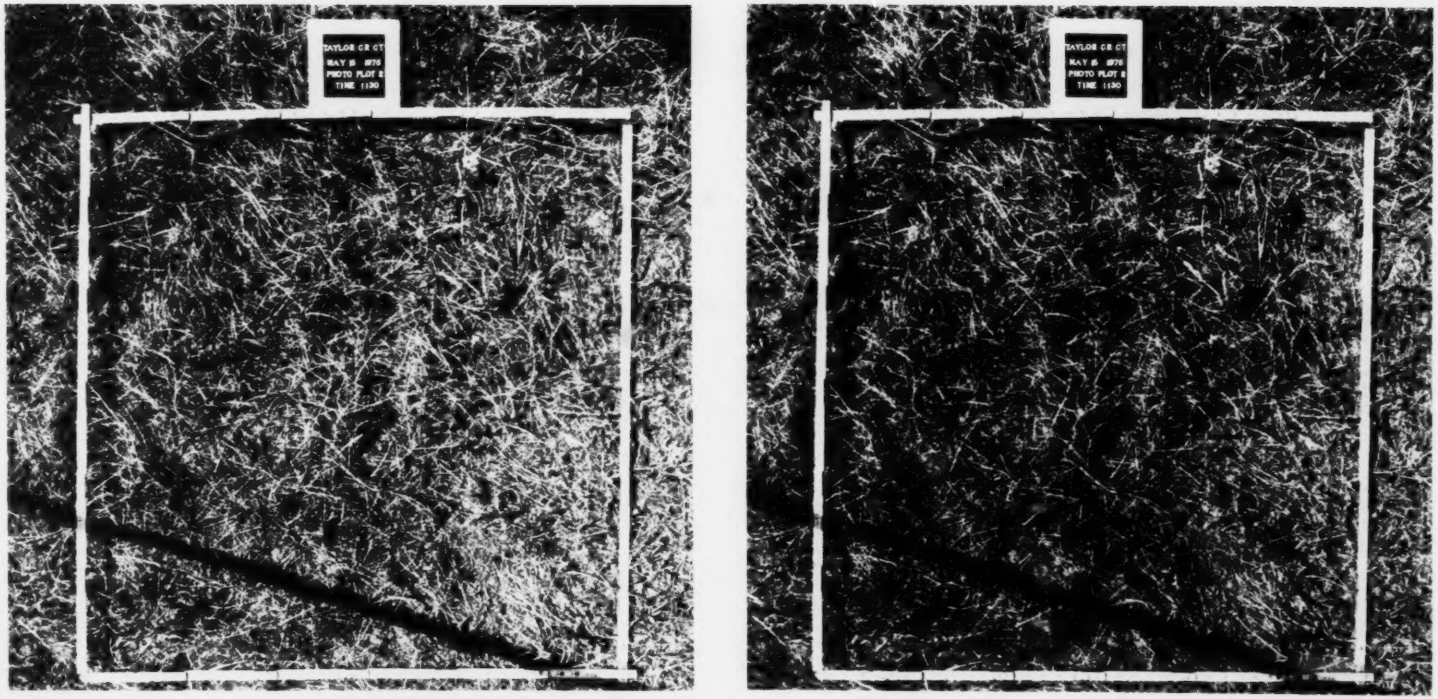

TAYLOR CR CT
MAY 15 1976
PHOTO PLOT 2
TIME 1130

Figure II-5 . Sample Sterogram

height estimates using the principle of stereoscopic parallax.

The 1975 photographic plot setup is shown in Figures II-6 and II-7. Studies of optimum film/filter combinations and exposure standardization will be made.

Aerial Photography. On September 24 and 25, initial aerial photography of the study areas was conducted by Aerial Survey, Inc. of Miles City. This activity was designed to obtain imagery in various emulsion types and at different scales to be evaluated for future operations. Color, infrared color, and black-and-white imagery was obtained in 35 mm and 70 mm formats. Flying elevations ranged from 500 to 7200 feet above ground level, yielding image scales from 1:3000 to 1:44,500. To aid in future aerial photography work, black-and-white index mosaics were prepared for each study area. The color imagery will be examined for use as a monitoring technique.

Enlargements of Hay Coulee 70 mm aerial photographs show that conventional color at a negative scale of 1:3000 will yield prints of 1:500 with sufficient resolution to map plant communities and conspicuous species. These photographs also show impacts of travel and sampling in the exclosure area.

Medium scale (1:10,000) aerial photography was viewed stereoscopically to aid in exact placement of exclosure sites on U. S. Geological Survey topographic maps. This imagery proved useful as a guide to interpretation of smaller scale photography acquired elsewhere.

Figure II-6 Stereoscopic Photo Plot Setup. Two EL/M Hasselblad cameras are operated simultaneously with the remote command unit.

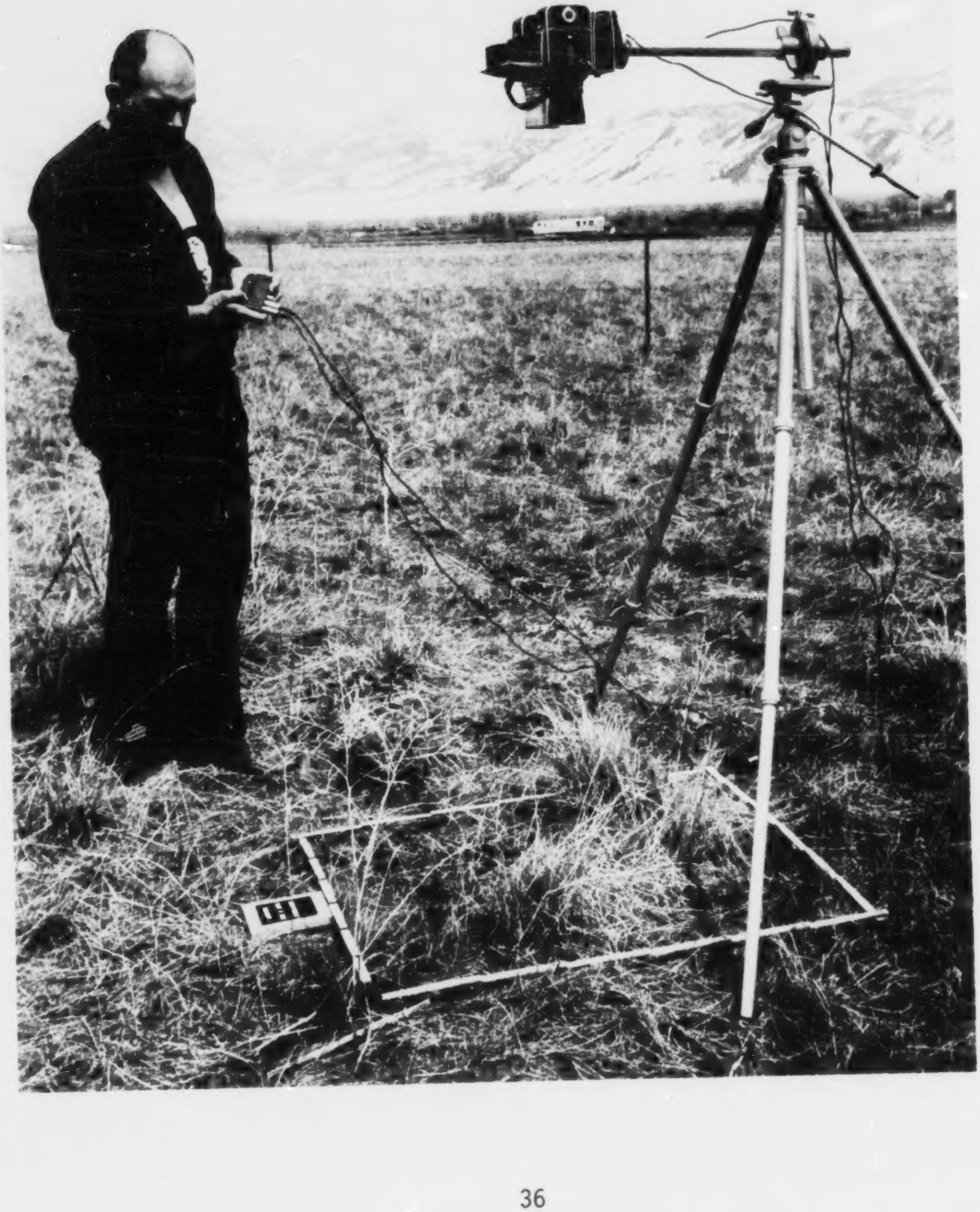
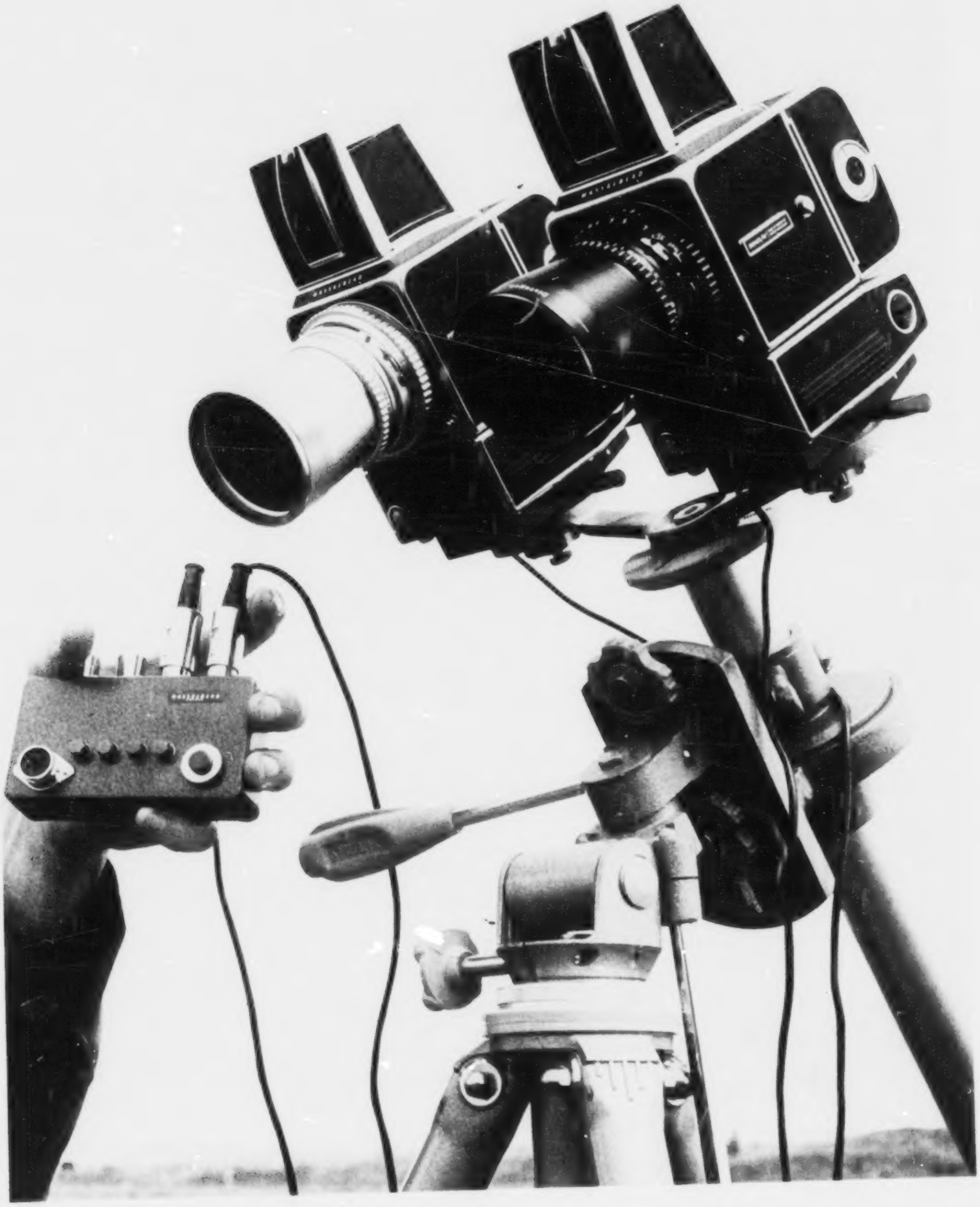


Figure II-7 Detail of Camera, Mount and Command Unit.



Future Plans

Methodology and field techniques for 1975 will be essentially the same, with a few modifications. Use of the fixed or random line placement method, rather than both, is a possible modification in field techniques. A first line analysis of last year's data using the fixed line placement method is complete. If statistical tests show no significant differences between the two line placement methods, then only one type would be needed. This would represent a reduction of 50 percent in the number of Daubenmire frames needed, a considerable savings in time, energy and money.

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SECTION III

EFFECTS OF SO_2 AND OTHER COAL-FIRED POWER PLANT EMISSIONS ON PRODUCER, INVERTEBRATE CONSUMER, AND DECOMPOSER STRUCTURE AND FUNCTION IN A SOUTHEASTERN MONTANA GRASSLAND

by

J. L. Dodd, R. G. Woodmansee, W. K. Lauenroth,
R. K. Heitschmidt and J. W. Leetham

INTRODUCTION

The primary objective of this research is to determine the effects of coal-fired power plant emissions on the structure and function of a Southeastern Montana grassland ecosystem, to replicate these effects in a total system simulation model, and to integrate these results with those of other program elements to satisfy overall project goals (see previous chapter of this report, by Lewis, Lefohn, and Glass).

One set of objectives relates to baseline monitoring of four grassland study sites, near the coal-fired power plant at Colstrip Montana (Hay Coulee, Cow Creek, North Pasture, and School Section) (Taylor, Leininger, and Fuchs, 1975). After the plant is completed (fall, 1975) these sites are expected to experience different intensities of atmospheric pollution. Project objectives for 1974 were designed to characterize seasonal biomass dynamics of the producer and invertebrate consumer components of each of these sites in the season prior to first exposure to power plant emissions. Objectives for 1975 are to determine the effects of the anticipated atmospheric pollution on these and other selected ecosystem attributes.

A second series of objectives relates to the experimental field study located near the Fort Howes Ranger Station in the Custer National Forest. On this site we will attempt to determine the effects of three levels of

SO_2, a major component of power plant emissions, on the seasonal biomass dynamics of the producers and invertebrate consumers and on decomposition rates.

A final set of objectives pertains to the adaptation of the Natural Resource Ecology Laboratory's ecosystem level simulation model to the grassland type discussed in previous objectives. The objectives for 1974 were to secure the field information necessary to prepare the model for simulation of control conditions. Future activities (1975, 1976) will consist of modifications of the model that will allow simulation of the dynamics of the Montana grassland under challenge from atmospheric pollution.

1974 FIELD SEASON PROGRESS

I. Primary Producer Biomass

A. Seasonal biomass dynamics and primary productivity estimates. This work was completed and is discussed in Appendix A.

B. Phenology

No phenology data were collected in 1974 due to a late starting date.

C. Species lists

Species lists compiled in 1974 included only those species occurring in the 0.5 m^2 quadrats clipped for aboveground biomass and were presented in the first interim report.

D. Chemical analyses

Tables III-1 through III-4 summarize the chemical analyses for the major herbage components. In addition, all aboveground plant material is being saved for future analyses. Analyses for ash content are complete but not summarized; analyses for total sulfur are in process.

II. Soil Respiration

No soil respiration data were collected in 1974 due to a late starting date.

III. Decomposition Bags

A. Litter

No litter bag samples were collected in 1974 due to a late starting date.

B. Cellulose

Sixteen cellulose bags were placed in the field per treatment (exclosure) in the spring, 1974. Three collections of four bags per treatment (exclosure) were completed in 1974. These data are not yet summarized.

IV. Invertebrates

A. Aboveground invertebrates

Samples were collected in conjunction with plant biomass samples.

Table III-1. NITROGEN (N) AND PHOSPHORUS (P) CHEMICAL ANALYSIS OF ABOVEGROUND OLD DEAD MATERIAL EXPRESSED IN WEIGHT PERCENTAGE.

TREATMENT[a/]	A				B				C				D				E				F				G				H			
ANALYSIS	N		P		N		P		N		P		N		P		N		P		N		P		N		P		N		P	
REPLICATION	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Agropyron smithii																																
MAY	.600		.057														.585[b/]		.062		.580		.057		.635		.047		.675		.061	
JUN									.595	.574	.060	.051	.709	.532	.047	.042	.589	.558	.057	.059	.440		.046									
JUL	.640	.630	.083	.063	.590	.630	.071	.063	.545	.505	.062	.057	.490	.520	.059	.068									.515		.054		.725	.595	.075	.056
AUG																	.548	.564	.077	.198					.505	.620	.047	.048	.703	.703	.058	.057
SEP																																
Stipa comata																																
MAY																									.640		.071					
JUN																																
JUL																																
AUG																																
SEP																										.886						

[a/] Treatment: A, B, C, D, original fumigation plots at Ash Creek; E, Hay Coulee; F, Cow Creek; G, North Pasture; H, School Section

[b/] Composite sample of replications 1 and 2.

Table III-2. NITROGEN (N) AND PHOSPHORUS (P) CHEMICAL ANALYSIS OF ABOVEGROUND STANDING LIVE MATERIAL EXPRESSED IN WEIGHT PERCENTAGE

TREATMENT[a]	A				B				C				D				E				F				G				H			
ANALYSIS	N		P		N		P		N		P		N		P		N		P		N		P		N		P		N		P	
REPLICATION	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Agropyron smithii																																
MAY	1.680		.251		2.201	1.675	.239	.231	1.633	1.873	.274	.246	1.617	1.325	.235	.176	2.035[b] 1.262	1.231	.286 .194	.173	2.435 1.09	1.351	.253 .18	.144	2.065		.266		2.135		.239	
JUN		1.737 (1.305)		.225 (.2)																					1.16	1.355	.125	.154	1.205	1.32	.168	.16
JUL	1.385	1.3	.219	.202	1.25	1.34	.177	.204	1.38	1.295	.201	.188	1.225	1.485	.189	.19	.896	.806	.127	.103	.86		.099		.85	.984	.101	.093	.955	.945	.099	.095
AUG																																
SEP																																
Bromus japonicus																																
MAY	1.654		.308		1.852		.267		1.502		.279		1.367	1.299	.264	.219	1.755		.313		1.420		.255						1.600		.274	
JUN		1.466		.284																												
JUL																																
AUG																																
SEP																																
Stipa comata																																
MAY																					1.915 1.153	1.216	.232 .199	.149	1.820 1.3	1.155	.235 .156	.185	1.215			.177
JUN					1.24		1.59						1.2		.16						1.143	1.457	.174	.172	1.151	1.102	.162	.157				
JUL																																
AUG																																
SEP																																
Koeleria cristata																																
MAY																	1.252		.201													
JUN	1.335	1.35	.255	.219													1.236		.174													
JUL																																
AUG																																
SEP																																

a/ and b/See notes Table III-1

Table III-3. NITROGEN (N) AND PHOSPHORUS (P) CHEMICAL ANALYSIS OF ABOVEGROUND RECENT DEAD MATERIAL EXPRESSED IN WEIGHT PERCENTAGE

TREATMENT[a/]	A				B				C				D				E				F				G				H			
ANALYSIS	N		P		N		P		N		P		N		P		N		P		N		P		N		P		N		P	
REPLICATION	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Stipa comata																																
MAY																																
JUNE																																
JUL																																
AUG																					.533	.53	.079	.078	.685	.783	.102	.113				
SEP																		1.195[b/]		.132										.978		.081
Bromus japonicus																																
MAY																																
JUN																	.855	.897	.174	.173	.746	.736	.157	.139								
JUL																									.870		.173			.77		.14
AUG																	.597	.618	.089	.074	.497	.476	.067	.065	.677		.100			1.522		.173
SEP																		.592		.068										.636		.068
Koelaria aristata																																
MAY																																
JUN																																
JUL	.475	.465	.11	.09													.59		.088													
AUG																	.546		.069													
SEP																																
Bouteloua gracilis																																
MAY																																
JUN																																
JUL																																
AUG																																
SEP																		1.254	.229		1.195		.216		1.179		.200		1.280		.128	

a/ and b/ See Notes Table III-1

Table III-4. NITROGEN (N) AND PHOSPHORUS (P) CHEMICAL ANALYSIS OF ABOVEGROUND LIVE AND DEAD MATERIAL EXPRESSED IN WEIGHT PERCENTAGE.

TREATMENT[a/]	A				B				C				D				E				F				G				H			
ANALYSIS	N		P		N		P		N		P		N		P		N		P		N		P		N		P		N		P	
REPLICATION	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Bouteloua gracilis																																
MAY																	1.165[b/]		.145		1.380		.154		1.145		.137					
JUN																	1.080	1.226	.164	.166		1.195		.195								
JUL																									1.055	1.150	.183	.219		1.105		.155
AUG																														.955		.127
SEP																	1.069	.911	.202	.119		.829										

a/ and b/ See Table III-1

Six sample dates were completed for the Colstrip sites and two for the fumigation system at Fort Howes. Each sample date included 10 0.5 m^2 samples per treatment. Laboratory processing is complete. Preliminary statistical analysis and interpretation of the data are incomplete. A summary of the data is presented in Tables III-5 through III-8.

B. Belowground invertebrates

1. Macroarthropods. Ten soil cores per treatment (exclosure) were collected on each of the aboveground invertebrate sample dates. Processing and statistical analysis status are the same for aboveground macroarthropods. A summary of the data is presented in Tables III-9 through III-12.

2. Microarthropods. At this writing (May 1975) all 1974 soil microarthropod samples from both the Colstrip (Treatments E, F, G, H) and the fumigation system (Treatments A, B, C, D) sites have been sorted, identified and counted. These samples represent five sample dates from Colstrip and three sample dates from the fumigation system. Project staff have analyzed 320 soil core samples, 5 cm diameter by 10 cm deep (two 5 cm sections/sample). Data collected on one sample date from Colstrip (14 May 1974) have been summarized. Analysis of data from the remaining sample dates from both Colstrip and the fumigation system sites will be completed soon. With summary information from only one sample date available it is impossible to document soil microarthropod populations at the various sites for the season. However, the estimated total microarthropod population numbers and biomass at the four Colstrip sites on 14 May 1974 are: Hay Coulee (Tr. E)--

Table III-5. SITE AG MACROARTHROPOD DATA SUMMARY
SAMPLE TYPE COL. TREATMENT E
FOR THE YEAR 1974
NUMBERS AND BIOMASS FOR TROPHIC
DEPTH - CM

	UNKNOWN		PLANT TISSUE		PLANT SAP		PLANT POLLEN		PREDATOR	
SD	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
110574	1.800	.00133	4.400	.02288	4.600	.00187	0.000	0.00000	2.200	.00375
250674	2.000	.00050	5.600	.01595	21.200	.00858	.600	.00062	10.400	.00752
50774	3.000	.00208	15.400	.02231	38.200	.01154	.600	.00227	13.000	.01346
10874	1.000	.00004	2.000	.01149	3.000	.00224	0.000	0.00000	2.600	.00220
180874	5.600	.00030	4.000	.01026	49.800	.00851	0.000	0.00000	3.800	.00303
120974	6.000	.00011	18.600	.02192	4.000	.00235	0.000	0.00000	8.600	.00229
MEAN	3.233	.00073	8.333	.11747	20.133	.00585	.200	.00048	6.767	.00537
T Weight Mean	2.848	.00073	7.245	.12587	20.605	.00604	.223	.00048	6.617	.00549

	PARASITE		OMNIVORE		SCAVENGER	
SD	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
110574	.400	.00044	1.800	.00039	1.000	.00687
250674	.800	.00109	2.400	.00040	.600	.00086
50774	0.000	0.00000	22.200	.00497	3.000	.00160
10874	0.000	0.00000	2.800	.00021	1.800	.00717
180874	1.000	.00017	.200	.00001	5.600	.00236
120974	1.200	.00070	2.600	.00065	.600	.00058
MEAN	.567	.00040	6.333	.00110	2.100	.00324
T Weight Mean	.540	.00042	4.964	.00101	2.090	.00341

Table III-6. SITE AG MACROARTHROPOD DATA SUMMARY
SAMPLE TYPE COL. TREATMENT F
FOR THE YEAR 1974
NUMBERS AND BIOMASS FOR TROPHIC
DEPTH - CM

	UNKNOWN		PLANT TISSUE		PLANT SAP		PLANT POLLEN		PREDATOR	
SD	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
140574	2.000	.00046	5.200	1.23385	14.000	.01084	0.000	0.00000	6.800	.00227
250674	2.400	.00068	8.000	.07199	23.400	.00876	2.000	.00470	7.000	.00754
70774	.200	0.00000	4.400	.06110	10.400	.00559	.200	.00046	4.400	.01118
40874	.600	.00004	1.800	.01063	11.600	.00455	0.000	0.00000	5.800	.00184
180874	.600	.00001	5.600	.02063	20.200	.00368	.200	.00007	2.800	.00269
130974	3.000	.00007	8.200	.02279	9.400	.00755	0.000	0.00000	4.600	.00526
MEAN	1.467	.00021	5.533	.23183	14.833	.00683	.400	.00087	5.233	.00513
T WEIGHT MEAN	1.430	.00025	5.489	.24105	15.603	.00691	.508	.00113	5.389	.00521

	PARASITE		OMNIVORE		SCAVENGER		NONFEEDING	
SD	NO/SQM	G/SQM	NO/SQM	G/SQM	N)/SQM	G/SQM	NO/SQM	G/SQM
140574	.600	.00030	26.000	.00527	2.600	.00716	.200	.00004
250674	.600	.00073	.600	.00015	11.000	.04016	0.000	0.00000
70774	.600	.00020	.800	.00006	4.600	.00678	0.000	0.00000
40874	.200	.00015	0.000	0.00000	1.400	.00014	.200	.00012
180874	.200	.00015	0.000	0.00000	10.000	.00506	.200	.00012
130974	.400	0.00000	2.000	0.00000	3.400	.01175	.200	.00012
MEAN	.433	.00025	4.900	.00091	5.500	.01184	.133	.00007
T WEIGHT MEAN	.444	.00030	4.952	.00095	5.879	.01334	.123	.00006

Table III-7. SITE AG MACROARTHROPOD DATA SUMMARY
SAMPLE TYPE COL. TREATMENT G
FOR THE YEAR 1974
NUMBERS AND BIOMASS FOR TROPHIC
DEPTH - CM

	UNKNOWN		PLANT TISSUE		PLANT SAP		PLANT POLLEN		PREDATOR	
SD	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
150574	4.800	.00226	13.000	1.86301	95.800	.02299	0.000	0.00000	13.600	.00734
230674	3.800	.00070	37.000	.04209	108.400	.03706	.400	.00012	14.600	.01387
70774	1.200	.00031	7.800	.03044	11.400	.00866	.200	.00007	6.000	.01037
50874	.600	.00002	3.800	.04112	18.200	.00417	.200	.00007	4.000	.00229
200874	.600	.00002	5.000	.02175	6.400	.00355	0.000	0.00000	5.000	.00259
200974	2.200	.00009	12.000	.02311	26.400	.00488	.200	.00007	9.600	.00870
MEAN	2.200	.00057	13.100	.33692	44.433	.01355	.167	.00005	8.800	.00753
T WEIGHT MEAN	2.197	.00056	13.955	.31142	46.427	.01458	.175	.00006	8.851	.00764

	PARASITE		OMNIVORE		SCAVENGER		NONFEEDING	
SD	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
150574	1.400	.00022	45.800	.00935	2.400	.00782	0.000	0.00000
230674	1.600	.00458	57.800	.01008	4.200	.01022	.200	.00007
70774	.400	.00193	1.000	.00059	3.200	.00306	0.000	0.00000
50874	.200	.00007	.400	.00004	3.400	.00033	.200	.00012
200874	0.000	0.00000	2.000	.00107	4.000	.00342	0.000	0.00000
200974	1.400	.00056	9.000	.00086	2.200	.00427	0.000	0.00000
MEAN	.833	.00123	19.333	.00366	3.233	.00485	.067	.00003
T WEIGHT MEAN	.816	.00139	20.630	.00391	3.342	.00501	.076	.00004

Table III-8. SITE AG MACROARTHROPOD DATA SUMMARY
SAMPLE TYPE COL. TREATMENT H
FOR THE YEAR 1974
NUMBERS AND BIOMASS FOR TROPHIC
DEPTH - CM

	UNKNOWN		PLANT TISSUE		PLANT SAP		PLANT POLLEN		PREDATOR	
SD	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
110574	2.600	.00273	6.600	.94378	7.200	.00227	0.000	0.00000	4.000	.00476
230674	9.400	.00736	12.400	.02576	45.600	.01711	.400	.00016	16.200	.00678
50774	11.000	.00126	15.600	.04508	11.200	.00495	0.000	0.00000	10.600	.00362
30874	2.200	.00007	2.600	.00931	4.000	.00170	0.000	0.00000	3.200	.00341
200874	2.600	.00004	2.600	.02025	1.600	.00052	.200	.00009	2.800	.00383
130974	6.800	.00019	2.200	.00336	8.800	.00228	0.000	0.00000	6.200	.00655
MEAN	5.767	.00194	7.000	.17459	13.067	.00480	.100	.00004	7.167	.00482
T WEIGHT MEAN	5.803	.00233	7.538	.18075	14.950	.00558	.121	.00005	7.634	.00479

	PARASITE		OMNIVORE		SCAVENGER		NONFEEDING	
SD	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
110574	.600	.00011	2.000	.00123	.800	.00308	.200	.00007
230674	.600	.00134	27.000	.00494	2.400	.00435	0.000	0.00000
50774	.800	.00187	2.400	.00118	9.600	.00833	.200	.00004
30874	.600	.00019	.200	.00014	1.200	.00014	.200	.00012
200874	.800	.00004	.600	.00032	6.800	.00370	0.000	0.00000
130974	.400	.00048	4.200	.00241	9.200	.00131	0.000	0.00000
MEAN	.633	.00067	6.067	.00170	4.833	.00348	.100	.00004
T Weight MEAN	.646	.00071	7.216	.00180	4.295	.00361	.104	.00004

Table III-12. SITE SOIL MACROARTHROPOD DATA SUMMARY
SAMPLE TYPE COL. TREATMENT H
FOR THE YEAR 1974
NUMBERS AND BIOMASS FOR TROPIC
DEPTH 0-15 CM

	UNKNOWN		PLANT TISSUE		PLANT SAP		OMNIVORE	
SD Da Mo Yr	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
120574	24.390	.00463	32.520	.01935	0.000	0.00000	32.520	.00813
230674	0.000	0.00000	8.130	.00683	0.000	0.00000	0.000	0.00000
190774	0.000	0.00000	0.000	0.00000	0.000	0.00000	8.130	0.00000
30874	8.130	.00008	8.130	.00423	0.000	0.00000	0.000	0.00000
190874	0.000	0.00000	8.130	.19073	0.000	0.00000	0.000	0.00000
110974	0.000	0.00000	56.911	.00472	8.130	.03659	0.000	0.00000
MEAN	5.420	.00078	18.970	.03674	1.355	.00610	6.775	.00136
T WEIGHT[1/] MEAN	5.231	.00081	15.561	.03670	.776	.00345	6.964	.00140

	SCAVENGER		NONFEEDING	
120574	0.000	0.00000	8.130	.00293
230674	8.130	.00780	0.000	0.00000
190774	0.000	0.00000	0.000	0.00000
30874	0.000	0.00000	0.000	0.00000
190874	0.000	0.00000	0.000	0.00000
110974	8.130	.00780	105.691	.06211
MEAN	2.710	.00260	18.970	.01084
T WEIGHT[1/] MEAN	3.032	.00291	11.362	.00636

[1/] Time weighted mean

Table III-10. SITE SOIL MACROARTHROPOD DATA SUMMARY
SAMPLE TYPE COL. TREATMENT F
FOR THE YEAR 1974
NUMBERS AND BIOMASS FOR TROPHIC
DEPTH 0-15 CM

	UNKNOWN		PLANT TISSUE		PLANT SAP		PREDATOR		PARASITE	
SD Da Mo Yr	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
120574	0.000	0.00000	8.130	.00683	8.130	.00098	8.130	.00016	0.000	0.00000
230674	0.000	0.00000	16.260	.01951	0.000	0.00000	0.000	0.00000	0.000	0.00000
190774	0.000	0.00000	0.000	0.00000	0.000	0.00000	0.000	0.00000	8.130	.04341
70874	24.390	.07569	0.000	0.00000	0.000	0.00000	0.000	0.00000	8.130	.00081
190874	0.000	0.00000	0.000	0.00000	0.000	0.00000	0.000	0.00000	0.000	0.00000
110974	8.130	.06333	16.260	.21919	0.000	0.00000	0.000	0.00000	0.000	0.00000
MEAN	5.420	.02317	6.775	.04092	1.355	.00016	1.355	.00003	2.710	.00737
T WEIGHT[1/] MEAN	3.865	.01559	7.464	.02727	1.399	.00017	1.399	.00003	2.532	.00811

	OMNIVORE		SCAVENGER		NONFEEDING	
SD	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
120574	40.650	.01333	16.260	.00951	8.130	.00163
230674	0.000	0.00000	0.000	0.00000	0.000	0.00000
190774	0.000	0.00000	0.000	0.00000	0.000	0.00000
70874	0.000	0.00000	8.130	.00780	8.130	.02537
190874	56.911	.01699	8.130	.00780	0.000	0.00000
110974	113.821	.02211	8.130	.00780	0.000	0.00000
MEAN	35.230	.00874	6.775	.00548	2.710	.00450
T WEIGHT[1/] MEAN	25.890	.00682	5.764	.00448	2.432	.00350

[1/] Time weighted mean

Table III-11. SITE SOIL MACROARTHROPOD DATA SUMMARY
SAMPLE TYPE COL. TREATMENT G
FOR THE YEAR 1974
NUMBERS AND BIOMASS FOR TROPHIC
DEPTH 0 - 15 CM

	UNKNOWN		ROOT TISSUE		ROOT SAP		PLANT TISSUE	
SD Da Mo Yr	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
120574	0.000	0.00000	0.000	0.00000	0.000	0.00000	0.000	0.00000
230674	8.130	.06333	0.000	0.00000	0.000	0.00000	8.130	.01480
190774	32.520	.00033	0.000	0.00000	0.000	0.00000	0.000	0.00000
70874	0.000	0.00000	16.260	.15935	8.130	.01033	16.260	.04488
190874	0.000	0.00000	0.000	0.00000	0.000	0.00000	0.000	0.00000
110974	16.260	.06951	0.000	0.00000	0.000	0.00000	0.000	0.00000
MEAN	9.485	.02219	2.710	.02656	1.355	.00172	4.065	.00995
T WEIGHT[1/] MEAN	9.796	.02426	2.066	.02025	1.033	.00131	4.332	.00983

	PLANT SAP		PREDATOR		PARASITE		OMNIVORE		SCAVENGER	
SD	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
120574	0.000	0.00000	24.390	.00593	0.000	0.00000	65.041	.01577	8.130	.00780
230674	8.130	.00130	8.130	.00033	0.000	0.00000	0.000	0.00000	0.000	0.00000
190774	0.000	0.00000	8.130	0.00000	0.000	0.00000	16.260	.00154	0.000	0.00000
70874	0.000	0.00000	0.000	0.00000	8.130	.03837	32.520	.01154	0.000	0.00000
190874	0.000	0.00000	8.130	.00195	0.000	0.00000	16.260	.00293	0.000	0.00000
110974	0.000	0.00000	8.130	.00439	0.000	0.00000	32.520	.00618	16.260	.01561
MEAN	1.355	.00022	9.485	.00210	1.355	.00639	27.100	.00633	4.065	.00390
T WEIGHT[1/] MEAN	2.266	.00036	9.896	.00181	1.033	.00487	23.724	.00547	2.932	.00281

Table III-11. (Continued)

	NONFEEDING	
SD	NO/SQM	G/SQM
120574	0.000	0.00000
230674	8.130	.00163
190774	0.000	0.00000
70874	0.000	0.00000
190874	0.000	0.00000
110974	164.472	.09577
MEAN	27.100	.01623
T WEIGHT[1/] MEAN	16.827	.00948

[1/] Time weighted mean

Table III-9. SITE SOIL MACROARTHROPOD DATA SUMMARY
SAMPLE TYPE COL. TREATMENT E
FOR THE YEAR 1974
NUMBERS AND BIOMASS FOR TROPHIC
DEPTH 0-15 CM

	UNKNOWN		PLANT TISSUE		PREDATOR		OMNIVORE	
SD Da Mo Yr	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM	NO/SQM	G/SQM
140574	32.520	.12764	8.130	.00691	8.130	.04065	8.130	.00691
230674	24.390	.09878	0.000	0.00000	0.000	0.00000	0.000	0.00000
190774	16.260	.06358	0.000	0.00000	8.130	.00244	8.130	.00203
120874	16.260	.06951	8.130	.00423	24.390	.12195	0.000	0.00000
190874	8.130	.06333	8.130	.00992	0.000	0.00000	0.000	0.00000
110974	24.390	.12667	24.390	.20919	0.000	0.00000	0.000	0.00000
MEAN	20.325	.09158	8.130	.03837	6.775	.02751	2.710	.00149
T WEIGHT[1/] MEAN	20.969	.09071	5.759	.02299	6.199	.02304	3.049	.00157

	NONFEEDING	
SD	NO/SQM	G/SQM
140574	0.000	0.00000
230574	0.000	0.00000
190774	0.000	0.00000
120874	8.130	.07805
190874	0.000	0.00000
110974	8.130	.00163
MEAN	2.710	.01328
T WEIGHT[1/] MEAN	1.829	.01024

[1/] Time weighted mean

131,026.5/m^2 for 82.2 mg/m^2; Cow Creek (Tr. F)--151,473.5/m^2 for 78.4 mg/m^2; North Pasture (Tr. G)-110,082.2/m^2 for 46.7 mg/m^2; School Section (Tr. H)--128,705.5/m^2 for 81.2 mg/m^2. These populations are much greater than those for a shortgrass prairie. A similar sampling on 5 May 1972 at the Pawnee Site in Colorado (a shortgrass prairie) gave an estimated population density of 52,499.0/m^2 (19.7 mg/m^2) and 39,180.9/m^2 (13.0 mg/m^2) in ungrazed and heavy grazed situations, respectively. With the exception of the North Pasture site, it appears that the Colstrip sites are quite comparable in soil microarthropod populations. Further comments on the data will be deferred until all summaries are complete.

V. Soil Description

This work is in progress; completion is scheduled for summer, 1975.

PLANS AND PROGRESS FOR THE 1975 FIELD SEASON

Plans for 1975 field work specify that seasonal biomass dynamics of primary producers and invertebrate consumers will be measured on six sample dates (17 April, 16 May, 10 June, 1 July, 1 August and 15 September) for each of the four Colstrip sites and for the four treatments of the SO_2 fumigation study near Fort Howes. Methods and procedures will be the same as for 1974. In addition to the previously mentioned work (biomass dynamics work, modeling and chemical analysis), soil water, plant phenology, decomposition, and soils description studies will be conducted as outlined in the continuation proposal for the 1975-1976 budget year.

Field work for 1975 has been initiated. Producer and invertebrate consumer biomass dynamics measurements are complete for two sample dates on all eight study sites. The project staff has aided in the establishment of several weather monitoring stations and the Zonal Air Pollution System (see subsequent chapter of this report, by Lee, Lewis, and Body).

Summaries and initial interpretation of all 1974 data should be complete by fall, 1975. Analysis and interpretation of most of the 1975 data from the fumigation study should be available by January, 1976.

REFERENCES

1. Taylor, John E., Wayne Leininger, and Ronald Fuchs. 1975. Site descriptions and effects of coal-fired power plant emissions on plant community structure. In: The Bioenvironmental Impact of a Coal-Fired Power Plant. (R. A. Lewis and A. S. Lefohn, eds.). Ecological Research Series, U.S. Environmental Protection Agency. Corvallis, Oregon. In press.

SECTION IV

INVESTIGATIONS OF THE IMPACT OF COAL-FIRED POWER PLANT EMISSIONS UPON PLANT DISEASE AND UPON PLANT-FUNGUS AND PLANT-INSECT SYSTEMS

by

C.C. Gordon

INTRODUCTION

Research on this component of the Montana Coal-Fired Power Plant Project began August 1, 1974. This report covers the work accomplished to date on our five main objectives and includes a discussion of the methodology used in the field and laboratory studies.

The major objective of our project component is to conduct extensive studies on species of flora and fauna surrounding Colstrip, Montana, prior to and after two 350-megawatt coal-fired power plants become operational. The work is to be conducted in such a way that predictive models can be generated and the results of our investigations can be integrated with those of the component investigations so that a predictive impacts assessment protocol can be generated. The first plant is scheduled to begin boiler testing in August, 1975; commercial generation should begin in October. Using baseline data gathered by the project investigators and the data collected after the power plants begin operating, project staff feel that a methodology can be developed that will predict the impact of coal-fired power plant emissions upon similar terrestrial ecosystems.

The University of Montana Environmental Studies Laboratory (ESL) portion of this project is designed to establish the baseline levels of (1) fungal populations (both beneficial and pathogenic), (2) insect populations (both beneficial and destructive), (3) the sulfur and fluoride concentrations within selected species of indigenous vegetation of the Colstrip area, (4) the chemistry of the area's precipitation, and (5) the growth of the predominant coniferous species, ponderosa pine.

These studies are being conducted on the six primary sites (Figure II-1) and 14 secondary sites (Figure IV-1; Table IV-1). The 14 additional sites were established in 1973 for a study the Environmental Studies Laboratory conducted for the Montana State Department of Natural Resources and Conservation. Five of the primary sites, located within 10 nautical miles of Colstrip, are in grasslands that are commonly dominated by western wheatgrass, needle and thread grass and sagebrush. The other sites, located within 20 nautical miles of Colstrip, are ponderosa pine plots in which common associates are skunkbush sumac (Rhus), bluebunch wheatgrass and ponderosa pine. The primary sites are located at lower elevations in the Colstrip area; the remaining sites are on ridgetops.

The insect survey and field and laboratory studies are presented in a separate section of this report by J. Bromenshank.

OBJECTIVE #1

A SURVEY STUDY OF THE INSECTS AND FUNGAL POPULATIONS, INFESTATION, AND DAMAGE TO INDIGENOUS PLANT SPECIES AT THE STUDY SITES OUTSIDE AND INSIDE THE IMPACT AREA

As indicated in the introduction, we are using the primary sites and 14 others in the preliminary survey studies of the fungal and insect populations. During the last nine months, surveys and collections were made at: Ash Creek, Hay Coulee, Cow Creek, North Pasture, School Section, and the relict knolls (A, B, and C).

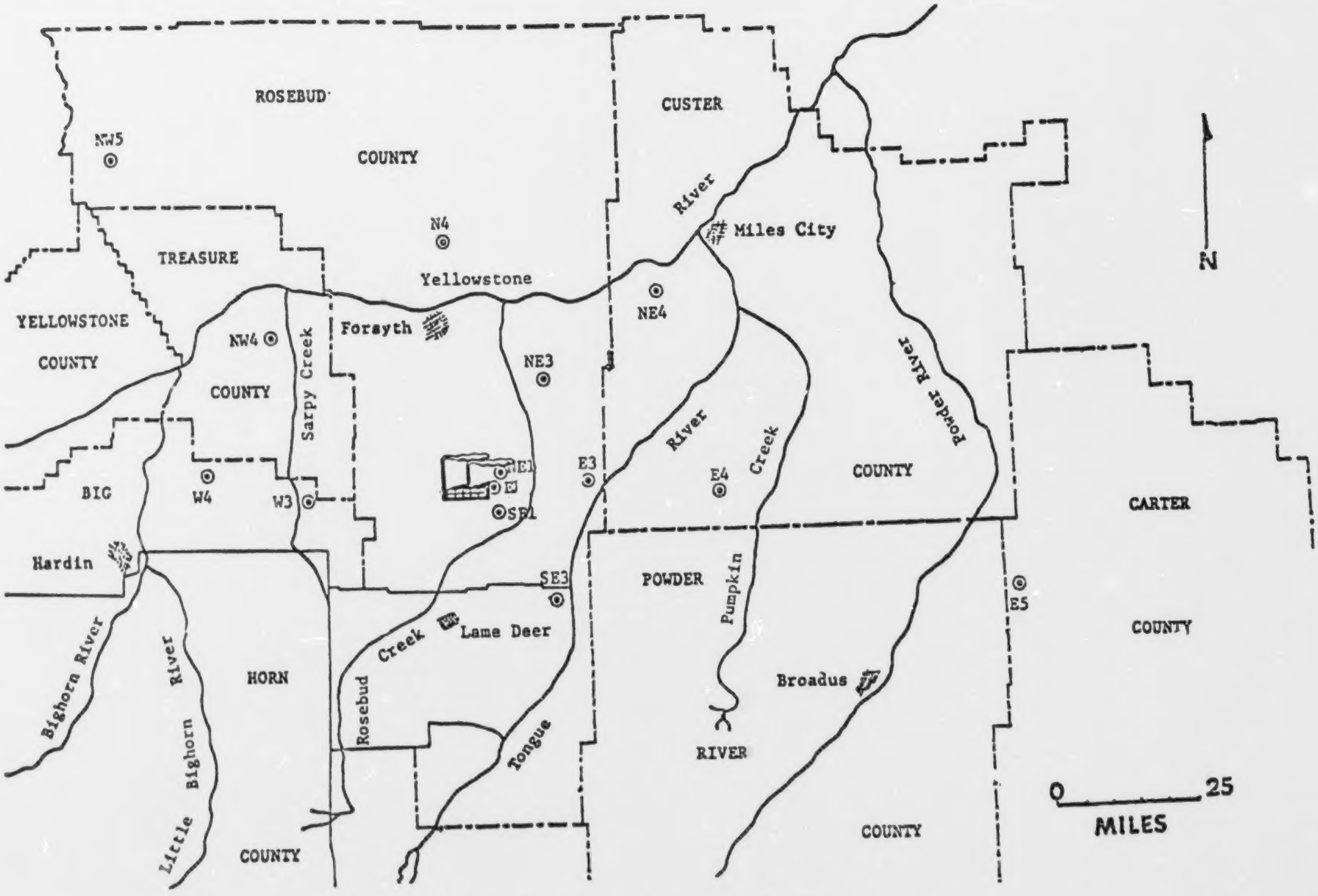

ROSEBUD
COUNTY
CUSTER
TREASURE
YELLOWSTONE
COUNTY
COUNTY
BIG
HORN
COUNTY
POWDER
RIVER
COUNTY
COUNTY
CARTER
COUNTY
NW5
N4
NW4
W4
W3
NE4
NE3
E1
SE1
E3
E4
SE3
E5
Yellowstone
River
Miles City
Forsyth
Sarpy Creek
Hardin
Bighorn River
Little Bighorn River
Rosebud Creek
Lame Deer
Tongue River
Pumpkin Creek
Powder River
Broadus
N
0
25
MILES

Figure IV-1 Vegetation Collection Sites

Table IV-1. VEGETATION COLLECTION SITES IN THE VICINITY OF COLSTRIP, MONTANA. Also see Figure IV-1.

Site No.	Location
North #4	Sec. 36, T8N, R40E
Northeast #1	Sec. 16, T2N, R42E
Northeast #3	Sec. 10, T4N, R43E
Northeast #4	Sec. 17, T6N, R46E
East #1	Sec. 29, T2N, R42E
East #3	Sec. 27, T2N, R44E
East #4	Sec. 36, T2N, R47E
East #5	Sec. 18, T2s, R55E
Southeast #1	Sec. 16, T1N, R42E
Southeast #3	Sec. 17, T2S, R44E
West #3	Sec. 36, T2N, R37E
West #4	Sec. 8, T2N, R35E
Northwest #3	Sec. 16, T4N, R39E
Northwest #4	Sec. 2, T5N, R36E

Vegetation samples from each of these sites were collected three times since August 1, 1974. A herbarium sample has been prepared for each plant species collected; those species thus far collected are on deposit and appropriately labeled at the University of Montana Botanical Herbarium.

Identification of the insect fauna present on the vegetation collected from the sampling sites is by Jerry Bromenshenk, entomologist. C. C. Gordon, plant pathologist and mycologist, is identifying the fungal species.

The identification of fungi and insects is done almost entirely in the laboratory. Plant samples with symptoms of fungal disease are treated as follows:

> A temporary microscope slide is prepared of the plant tissue manifesting the tissue necrosis caused by the fungus. If the fungus is not an obligate parasite (a rust or smut), an attempt is made to isolate the organism by culturing on nutrient media.

To date, using this method 46 cultures of fungal isolates have been obtained (Table IV-2). Culturing of these fungi and new isolates will continue throughout the 1975 spring and summer until an adequately diverse group of fungi is obtained.

Samples of both obligate and saprophytic fungi have been prepared for histological studies, using the normal procedures of fixing in a solution of 95 percent ethanol: glacial acetic acid: formalin:water (126:10:10:54), dehydrating in the tertiary butyl alcohol series, and mounting in paraffin. Thus far, 54 fungi damaged or infected specimens have been prepared for microtoming. Sectioning of the materials is

Table IV-2. FUNGAL CHECKLISTS OF IDENTIFIED CULTURES

Number	Fungus	Hosts obtained from:
1	Septoria avenae	Agropyron smithii A. spicatum
2	Ascohyta agropyrina	Agropyron smithii
3	Hendersonia sp.	Stipa comata
4	Fusarium solani	Koeleria cristata
5	Penicillium spp.	Stipa comata Agropyron spicatum Melilotus alba
6	Aspergillus spp.	Agropyron spicatum A. smithii Koeleria cristata etc.
7	Leptosphaeria artemisiae	Artemisia cana A. tridentata
8	Phyllosticta sp.	A. tridentata
9	Tubercularia vulgaris	Symphoricarpos occidentalis
10	Alternaria sp.	Rhus trilobata Chrysothamnus viscidiflorus
11	Cladosporium sp.	Petalostemon purpureum
12	Verticillium sp.	Artemisia frigida

completed and photomicrographs have been taken of most specimens. Special emphasis for histological studies has been given to the fungi parasitizing the grass species since at the NERL stress site, grasses are the most abundant species.

OBJECTIVE #2

ANALYSIS AND SELECTION OF INDIGENOUS PLANT SPECIES WHICH HAVE A DIVERSIFIED BUT UNDERSTANDABLE INTERRELATIONSHIP WITH THE INSECT AND FUNGAL POPULATIONS AT THE STUDY SITE

Histological studies of vegetation collected from the study sites being parasitized or decomposed by fungal saprophytes were conducted during the 1974 fall and winter. The studies were not continued in detail from January to June, 1975 since the scientist who performs this work was on a six-month sabbatical leave.

In these studies on host-parasite and host-saprophyte relationships using histological methods, the major concern is to make sure that some fungi are selected which have exogenous growth habits and some with endogenous growth habits on their respective host species. While the available literature regarding the identification of fungal species is adequate to identify both cultured and sectioned specimens, there is little discussion in the literature of the host-parasite relationship of those fungi that we have thus far studied.

During the 1975 summer and fall considerable time will be spent on inoculation studies with the fungal cultures thus far obtained, and with the host species grown in the field and at selected collecting sites in the Colstrip area.

OBJECTIVE #3

SELECTION AND PRETESTING FOR EASE OF IN-VITRO GROWTH AND INOCULATION STUDIES OF DISEASE- AND INJURY-CAUSING FUNGAL AND INSECT SPECIES TO BE UTILIZED AT STUDY SITES INSIDE AND OUTSIDE THE IMPACT AREA

Of those fungi species isolated into pure culture and identified so far, there is a predominance of Moniliales and Sphaeropsidales which belong to the class Fungi Imperfecti (Deuteromycetes). The species of Moniliales, especially the isolates of *Fusarium*, *Penicillim* and *Aspergillus*, are not known to be strongly parasitic to any of the host plants from which they were isolated. They are, in fact, likely to be soil contaminants of the plant. However, several of these Moniliales isolates are being maintained for inoculation studies this winter. Species of the Spaheropsidales isolated to date are known pathogens or saprogens of the hosts from which they were isolated. Three of the general isolated (*Septoria avenae*, *Phyllosticta* sp. and *Hendersonia*) have been cited as common saprophytes and/or parasites of indigenous grasses of the Colstrip area. The isolation, culturing, identification, and inoculation pretesting of fungi will be a major effort this summer.

OBJECTIVE #4

SELECTION AND PRETESTING OF BENEFICIAL FUNGAL AND INSECT SPECIES TO BE UTILIZED AT STUDY SITES INSIDE AND OUTSIDE THE IMPACT AREA

See studies of insects.

Fungal studies were not conducted during the last quarter since the lead researcher was on sabbatical. See discussion of Objectives 1, 2, and 3 for description of work completed in first two quarters.

OBJECTIVE #5

CHEMICAL ANALYSIS OF INDIGENOUS PLANTS, INSECTS AND FUNGI WHICH ARE SELECTED FOR INTENSIVE INVESTIGATION DURING SECOND AND THIRD YEARS OF PROPOSED STUDY

I. METHODS

Types and Methods of Vegetation Collection

Each of 14 sampling sites was divided into four subsections for sample collection. In each subsection, ponderosa pines were identified as the primary indicator species for air pollution impact; the grasses, shrubs and/or other vegetation were collected in the immediate vicinity. Each pine selected at each site was permanently marked with an aluminum tag containing the sample number. At the NERL sampling plots where no pines grow, only grasses, shrubs and other vegetation were collected.

Branches of ponderosa pine (with foliage) were collected from the top third of the tree on the side of the crown facing Colstrip. The branches were removed from the tree by shooting them down with a shotgun.

Grass foliage was clipped at least one inch above ground level. Shrub foliage was collected by removing those branches holding foliage. Yucca samples were obtained in the same manner as grasses, and juniper the same as shrubs.

Immediately after collection, each sample was placed in an individual plastic sack with a card identifying the sample, collection date, plot location, and sample number. This information was recorded in the field diary with other pertinent information. When collection at a given plot was complete, samples were placed in a duffle bag for transportation to the University of Montana.

As soon as possible after collection, the samples were transported to the University of Montana. In no case did more than seven days lapse between collection time and delivery. The average time from field collection to laboratory was four days. Upon arrival at the University of Montana, samples were stored in a walk-in cooler.

Preparation of Vegetation for Chemical Analysis

As soon as practical after receipt at the laboratory, the foliage of each sample was removed according to year of growth in the case of pines, or as a composite in the case of other plants. Samples were placed in a paper sack containing the sample number and foliage year, if appropriate. The samples were either transferred to a forced draft oven or stored in boxes until oven room was available. After drying under forced draft for at least three days at 90°F., the samples were ground in a Wiley mill to pass 40 mesh, placed in a 30 dram vial with an identifying label, and stored in a plastic sack by site until analyzed.

Each step in the analysis procedure was recorded on a permanent sample log sheet. This sheet contained the sample number, date collected, species, collector's name, site, with space for other observations. Also, the sample type, year of foliage or composite, and dates dried, ground, and analyzed were recorded on the log. Finally, the results of all analyses were entered.

Fluoride Analysis of Vegetation

The method of fluoride (F^-) analysis of vegetation used in this study was developed in 1970 at the University of Montana Environmental

Studies Laboratory. It incorporates the Orion fluoride specific ion electrode as the fluoride sensor. The method is precise and rapid, and the results of comparative studies using other techniques show good agreement.

Precisely 0.50 g of dried, ground plant material was placed in a 35 ml. nickel crucible with 0.05 g of low fluorine calcium oxide and slurried with distilled water. The slurry was dried and then charred by infrared radiation, transferred to a muffle furnace, and ashed overnight at 600°C. The crucibles were covered during ashing.

When the crucibles were cool, the ash was moistened with distilled water, dissolved in a minimum of 30 percent perchloric acid, increased to 100 ml. with 50 percent TISAB, transferred to a plastic beaker, placed on a magnetic stirrer, and the electrodes inserted into the stirred solution. The solution was insulated from the heat of the stirrer with a half inch of sponge and the millivolt (MV) reading was recorded after the electrodes had equilibrated.

Immediately prior to sample analysis, the electrodes were calibrated with standard solutions of the following fluoride concentrations: 0.05, 0.10, 0.50, 1.0, 5.0, 10.0, and 19.0 ppm. A calibration curve was prepared by plotting millivolt reading as a function of fluoride concentration on semilogarithmic graph paper, and the fluoride content of unknowns was determined by interpolation from the graph and the following calculation:

$$\text{Ppm F}^- = \left(\frac{\mu\text{gF}^-/\text{ml}}{\text{Sample Wt. in G.}}\right) \times 100$$

Samples with fluoride concentrations falling below the useful range of the calibration curve were treated by adding sufficient fluoride to bring them into millivolt range. For most plant materials, 1 ml. of a

5.0 ppm F^- solution was sufficient. Reagent blanks were carried through the entire procedure with each series of samples.

As an alternative to the manual determination of fluoride concentration of unknowns, the preparation of the calibration curve, the interpolation and the calculation of the flouride concentration of unknown samples may be computerized according to the BASIC program.

Sulfur Analysis of Vegetation

The total sulfur (S) content of vegetation was determined by a combustion iodometric procedure employing a Leco induction furnace to generate SO_2 and titration of the SO_2 with potassium iodate (Laboratory Equipment Corporation, undated). An aliquot of dried, ground plant material was weighed into a crucible, tin and iron metal catalysts were added, and the crucible was placed into the furnace induction field. The sample was combusted in an oxygen atmosphere to generate SO_2 which was bubbled through a solution of iodine and starch. Sulfur dioxide generated in the furnace bleaches the solution of starch and free iodine by the following reaction:

$$SO_2 + I_2 + H_2O \rightarrow H_2SO_4 = 2HI$$

The blue color was maintained by titrating the starch solution with potassium iodate:

$$KIO_3 + 5KI + 6HCL \rightarrow 6KCl + 3I_2$$

The titration continued until SO_2 generation was complete, as evidenced by the maintenance of blue color in the starch solution without adding KIO_3 (Laboratory Equipment Corporation, undated).

Recovery Studies

To determine recovery efficiency of the combustion iodometric method for the analysis of total sulfur in plant material, three separate experiments were performed. First, aliquots of potassium aluminum sulfate were analyzed (Table IV-3). Second, known amounts of thiourea (NH_2CSNH_2) were adsorbed onto cellulose to give varying concentrations of sulfur in cellulose, and these standards were then analyzed (Table IV-4). Finally, cellulose standards and plant samples were mixed to determine the effect of plant material on the recovery of sulfur from the standards (Table IV-5). Sample aliquots of 0.1 g were used to obtain the data presented Tables IV-4 and IV-5. Preliminary work indicated that such aliquots of plant material resulted in good combustion without violence and ready conversion to percent sulfur in the sample. The data in Table IV-5 show that the lowest recoveries were obtained with the largest volume of plant material and the smallest volume of cellulose-thiourea.

The average sulfur content of *Pinus* foliage collected away from areas subjected to sulfurous air pollution has been previously reported. Katz and McCallum (1939) report average total sulfur concentrations of .09 to .13 percent. Thomas, Hendricks, and Hill (1950) report average sulfur content in different years' conifer foliage ranging from .10 to .11 percent. They indicate that organic sulfur in conifers normally is about .1 percent. The data of Kieley and Lambert (1972) indicate that sulfate-sulfur in the foliage of *Pinus radiata* averages less than .025 percent.

These previous studies appear to indicate that species of *Pinus* found away from sources of sulfurous air pollution may contain most of their sulfur as organic sulfur and possibly less than 250 ppm of their total sulfur as inorganic sulfur. Therefore, the efficiency of recovery

Table IV-3. RESULTS OF ANALYSES OF POTASSIUM ALUMINUM SULFATE ($KAl(S)_4)_2$) AS THE SOURCE OF SULFUR FOR SO_2 GENERATION

Grams S x 10^{-5} Added	Grams S x 10^{-5} Recovered
46.5	43
46.5	43
46.5	47
36.4	33
30	29
30.3	29
24.8	22
24.2	21
24.6	13
17.8	16
18.2	16
13.5	13
10.7	11
9.4	9
10	9

Table IV-4. RESULTS OF ANALYSES OF SYNTHETIC PLANT STANDARDS PREPARED BY ADSORBING THIOUREA ON PURE CELLULOSE

Ppm S Concentration in Cellulose-Thiourea	Ppm S Concentration in Cellulose-Thiourea Recovered by Analysis	Average
10000	9200	9200
5000	4700	4666
	4600	
	4700	
3000	2800	2866
	2800	
	3000	
2500	2300	2333
	2400	
	2300	
1500	1500	1433
	1500	
	1300	
1000	900	933
	1000	
	900	
500	500	533
	500	
	600	
0	0	0
	0	
	0	

Table IV-5. RESULTS OF SULFUR RECOVERY FROM SYNTHETIC PLANT STANDARDS
PONDEROSA PINE MIXTURES

Ppm S in Cellulose	Weight (g) Cellulose	Weight (g) P. Ponderosa	Ppm S Recovered	Average
2500	.025	.075	2000	2200
"	.025	.075	2400	
2500	.05	.05	2700	2433
"	.05	.05	2500	
"	.05	.05	2100	
1500	.05	.05	1500	1366
"	.05	.05	1400	
"	.05	.05	1200	
1000	.01	.09	800	700
"	.01	.09	700	
"	.01	.09	600	
500	.05	.05	500	500
"	.05	.05	500	

for the combustion iodometric method used in this study was based upon the results of recovery studies employing cellulose-thiourea standard and plant sample mixtures.

Because the lowest recoveries were obtained with the largest amount of plant material relative to the cellulose standard (Table IV-4), a graph was prepared (Figure IV-2) from which a given analysis of plant material could be increased by an amount of sulfur reflecting the low recovery. The recovery results of 2200 ppm S for a 2500 ppm concentration, and 700 ppm S for a 1000 ppm concentration were used to prepare Figure IV-2. Thus if a given analysis of plant material resulted in a concentration of 1500 ppm S (X-axis, Figure IV-2), the result to be reported is 1800 ppm s (Y-axis, Figure IV-2).

Method of Sulfur Analysis

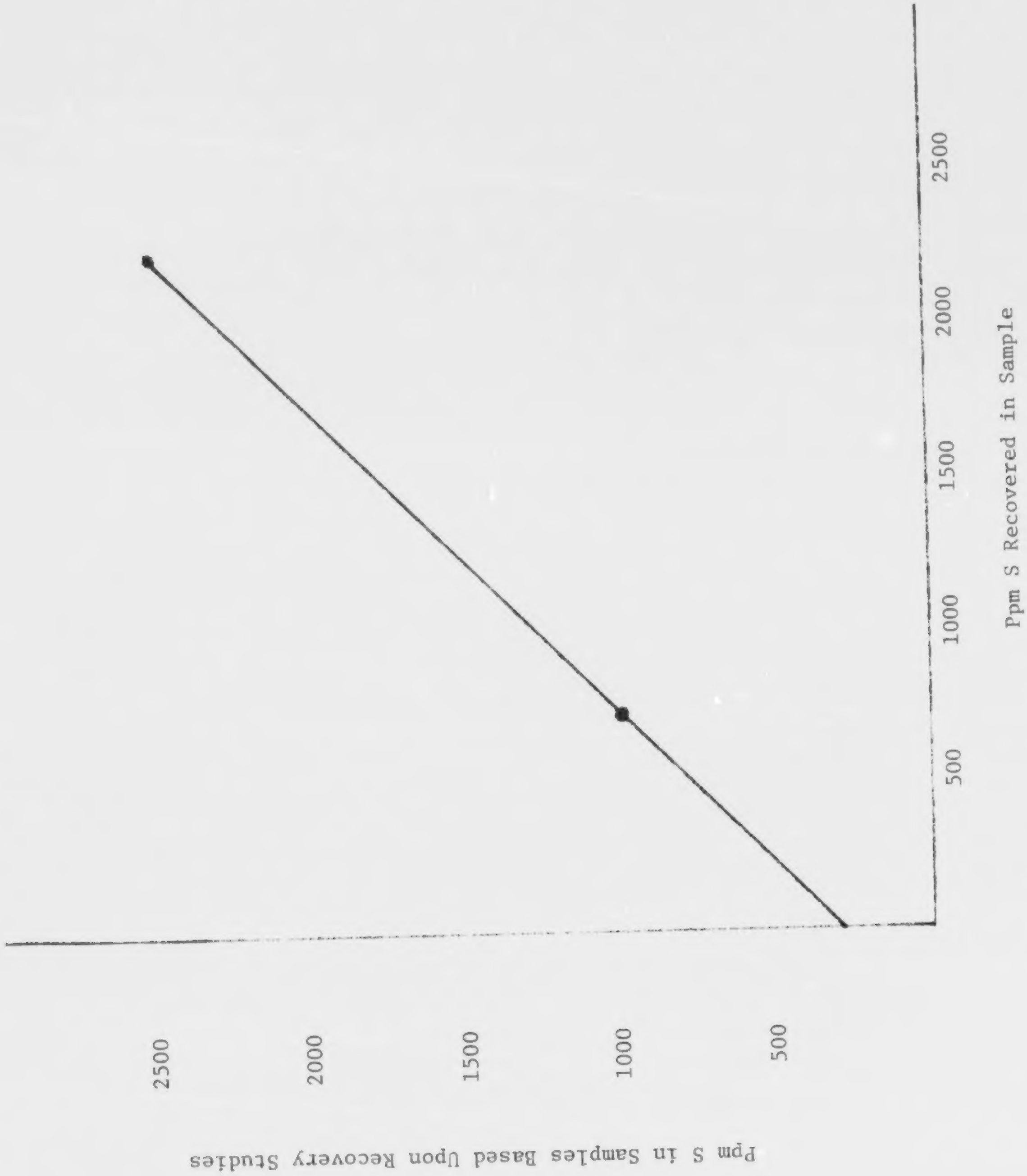
The following method is used in the sulfur analysis process:

> Weigh 0.10 g of dried, ground plant material into a combustion crucible, add 1 scoop of iron and 2 scoops of tin metal. Add starch and HCl to the titration vessel, and titrate KIO_3 until the endpoint blue color is reached. Record the burette reading. Cover the crucible and place in the induction furnace. Titrate with KIO_3 to keep the endpoint blue color until the solution is no longer bleached. Record the resultant burette reading. Determine the total sulfur content by use of Equations I and II (below). Report the results as ppm S.

Equation I:

Percent S = (Final Burette Reading - Initial Burette Reading) - Blank

Figure IV-2 Recovery Efficiency of the Combustion Iodometric Method for the Analysis of Total Sulfur. See accompanying text.



Equation II:

Ppm S = (Percent S) (10^4) + Increase from Figure IV-2.

II. RESULTS

Four to five separate samples of each species of trees, shrubs, forbs, and grasses collected from each of the 14 ESL field sites during the 1974 fall and winter were analyzed for sulfur and fluoride. Over 1100 fluoride and sulfur analyses have been completed since the Second Quarterly Report on more than 540 samples of vegetation. A tabular listing of each sample from each site is included in Appendix B. The fluoride and sulfur analyses completed on Bromenshenk's plant and insect speciments are reported in another section of this report.

Statistical analysis of the fluoride data accumulated this winter has been started; new results have not been compared to collections from previous years at these same sites. However, examination of the 1974 data shows that the mean for any given species will not exceed 4 ppm of fluoride and that none of the pine samples will exceed 3 ppm of fluoride.

Table IV-6a shows the sulfur data obtained from analyzing vegetation samples collected at the five primary sites and the Ash Creek site. The fluoride data for these 40 vegetation samples were reported in the Second Quarterly Report. However, the sulfur analyses had not been completed at that time. They are presented in this report in Table IV-6b.

Comparison and statistical analysis of the sulfur data accumulated this winter with data from other year's studies are not completed; results will be reported in the Fourth Quarterly Report.

Table IV-6a. Sulfur Data from Vegetation Samples Collected at the Primary Sites and Ash Creek Site.

F#	Species	Location	Ppm S
2413-A	Artemisia ludoviciana	Ash Creek - 1 acre	1100
2414-A	C. viscidiflorus	Same	2200
2415-A	Artemisia cana	Same	2000
2416-A	Aristidalongiseta	Same	900/1000
2417-A	C. viscidiflorus	Ash Creek - 25 acre	1300
2418-A	Artemisia cana	Same	1600
2419-A	Aristida longiseta	Same	700
2420-A	C. viscidiflorus	Same	1400
2421-A	A. ludoviciana	Same	700
2422-A	Aristida longiseta	Same	700
2423-A	Artemisia cana	Same	2400/2400
2424-A	C. viscidiflorus	Same	1300
2425-A	Aristida longiseta	Same	700
2426-A	Artemisia cana	Same	2400/2500
2427-A	Artemisia cana	Hay Coulee - 1 acre	1800
2428-A	Bromus tectorum	Same	500
2429-A	Chrysothamnus viscidiflorus	Same	1500
2430-A	A. tridentata	Same	1100
2431-A	Artemisia cana	Same	1700
2432-A	Bromus tectorum	Same	500/500
2433-A	Andropogon scoparius	Same - 50 yd. North	400/300
2434-A	Stipa comata	" " " "	600
2435-A	Artemisia cana	School Section	1600
2436-A	Stipa comata	Same	700
2437-A	Artemisia cana	Same	2200
2438-A	Aristida longiseta	School Section	600
2439-A	Artemisia cana	Same	2200
2440-A	Aristida longiseta	Same	700

Table IV-6a (Continued)

F#	Species	Location	Ppm S
2441-A	Andropogon scoparius	Relict Knolls	400
2442-A	Artemisia cana	Same	2000
2443-A	Chrysothamnus viscidiflorus	Same	1200
2444-A	Second growth medicago	Same	2500/2000
2445-A	Aristida longiseta	North Pasture	550
2446-A	Bromus tectorum	Same	500
2447-A	Aristida longiseta	Same	600/600
2448-A	Bromus tectorum	Same	800
2449-A	A. frigida	Same	800
2450-A	Stipa comata	Same	700
2451-A	Bromus tectorum	Cow Creek	400
2452-A	Aristida longiseta	Same	400
2453-A	Bromus tectorum	Same	700
2454-A	Aristida longiseta	Same	600
2455-A	Bromus tectorum	Same	300
2456-A	Aristida longiseta	Same	700

Table IV-6b. FLUORIDE CONCENTRATIONS IN VEGETATION FROM COLSTRIP EPA STUDY AREA EXCLOSURES

F#	Species	Location	Ppm F$^-$
2413-A	Artemisia ludoviciana	Ash Creek - 1 acre	5.7
2414-A	Chrysothamnus viscidiflorus	" "	5.9
2415-A	Artemisia cana	" "	4.7
2416-A	Aristida longiseta	" "	2.8
2417-A	Chyrsothamnus viscidiflorus	Ash Creek - 25 acre	3.6
2418-A	Artemisia cana	" "	1.7
2419-A	Aristida longiseta	" "	2.8
2420-A	Chrysothamnus viscidiflorus	" "	1.7
2421-A	Artemisia ludoviciana	" "	3.8
2422-A	Aristida longiseta	" "	3.2
2433-A	Artemisia cana	" "	4.1
2424-A	Chrysothamnus viscidiflorus	" "	3.0
2425-A	Aristida longiseta	" "	1.4
2426-A	Artemisia cana	" "	3.3
2427-A	" "	Hay Coulee - 1 acre	4.3
2428-A	Bromus tectorum	" "	2.6
2429-A	Chrysothamnus viscidiflorus	" "	3.2
2430-A	Artemisia cana	" "	3.6
2431-A	Artemisia cana	" "	3.8
2432-A	Bromus tectorum	" "	3.1
2433-A	Andropogon scoparius	" "	2.6
2434-A	Stipa comata	" "	2.5
2435-A	Artemisia cana	School Section	2.8
2436-A	Stipa comata	" "	3.4
2437-A	Artemisia longiseta	" "	2.5
2438-A	Aristida longiseta	" "	1.6
2439-A	Artemisia cana	" "	3.4

Table IV-6b (Continued)

F#	Species	Location	Ppm F$^-$
2440-A	Aristida longiseta	School Section	3.4
2441-A	Andropogon scoparius	Relict Knolls	1.5
2442-A	Artemisia cana	" "	2.5
2443-A	Chrysothamnus viscidiflorus	" "	6.1
2444-A	Medicago sativa	" "	1.7
2445-A	Aristida longiseta	North Pasture	2.7
2446-A	Bromus tectorum	" "	2.4
2447-A	Aristida longiseta	" "	3.3
2448-A	Bromus tectorum	" "	3.9
2449-A	Artemisia frigida	" "	3.0
2450-A	Stipa comata	" "	2.8
2451-A	Bromus tectorum	Cow Creek	2.1
2452-A	Aristida longiseta	" "	1.7
2453-A	Bromus tectorum	" "	1.7
2454-A	Aristida longiseta	" "	4.6
2455-A	Bromus tectorum	" "	3.6
2456-A	Aristida longiseta	" "	2.6

Tables IV-7a and IV-7b show the mean average results of sulfur and fluoride concentrations (as well as highest and lowest values) found in the various species of vegetation from all sites.

OTHER OBJECTIVES

I. PRECIPITATION CHEMISTRY

Five new automated Wong precipitation collectors were received in February, 1975. These collectors, however, were not put into operation until May because of needed modifications. Winter collections for 1974 were not made from the 14 bulk precipitation and 2 Wong collectors already located in the field. We are now collecting the winter precipitation samples and selected chemical and physical parameters of the winter samples will be carried out (pH, $SO_4^=$ concentration, fluoride, and conductivity). While much of the chemistry of the long-term bulk samples will be totally inconsistent with long-term wet and dry collectors such as the Wongs, pH, $SO_4^=$ concentration and conductivity vary considerably less than other parameters such as trace metal content (Galloway and Likens, in preparation). We expect some useful information to emerge from these analyses. Table IV-8 contains data on pH of rainwater samples collected during November, 1974.

An ancillary study to determine the measureable pH changes of small amounts (3/10 ml) of various acid solutions (H_2SO_4 and HNO_3) under differing humidities and temperatures is underway. This study was initiated because of the acid deposition-caused damage now occurring on the basal tissues of ponderosa pine needles at several sampling sites. A report of this experiment will be included in the next progress report since this study is short-term (two months) and will be completed soon.

Table IV-7a. MEAN, HIGH, AND LOW F^- CONCENTRATIONS IN EPA ENCLOSURES

Species	N	Mean	High	Low
A. ludoviciana	2	4.7	5.7	3.8
A. cana	10	3.3	4.7	1.7
A. tridentata	1	3.6		
A. frigida	1	3.0		
A. longiseta	11	2.7	4.6	1.4
C. viscidiflorus	6	3.9	6.1	1.7
B. tectorum	7	2.7	3.9	1.7
S. comata	3	2.9	3.4	2.5
2nd growth medicago	1	1.7		
COLSTRIP SITES				
P. ponderosa	'71 65	2.6	9.9	0.8
	'72 65	2.2	5.2	0.4
	'73 65	2.1	3.7	0.4
	'74 65	1.6	3.3	0.2
J. scopulorum	46	2.3	4.7	0.1
A. scoparius	57	2.1	7.2	0.1
A. spicatum	68	2.2	6.8	0.2
C. longifolia	11	1.4	2.0	0.7
R. trilobata	10	1.7	2.6	1.4
A. tridentata	16	3.6	5.6	1.8
A. cana	36	2.4	6.7	0.4
Y. glauca	5	1.7	3.1	0.8
C. viscidiflorus	6	2.8	3.7	1.7
C. nauseosus	2	2.3	2.9	1.8
A. longiseta	6	1.5	2.9	1.1
S. comata	10	2.5	4.5	1.3
O. hymenoides	4	2.5	4.2	1.2

Table IV-7**b**. MEAN, HIGH, AND LOW S CONCENTRATIONS IN EPA EXCLOSURES

Species		N	Mean	High	Low
A. longiseta		11	673	1000	400
A. cana		10	2066	2500	1600
A. tridenta		1	1100		
A. ludoviciana		2	900	1100	700
A. frigida		1	800		
C. viscidiflorus		6	1483	2200	1200
B. tectorum		7	525	800	300
S. comata		3	366	400	300
A. scoparius		2	366	400	300
2nd growth medicago		1	2250		
			COLSTRIP SITES		
P. ponderosa	'71	65	655	1000	450
	'72	65	677	900	400
	'73	65	723	1100	400
	'74	65	676	1000	400
A. canas		36	2372	3400	1700
J. scopulorum		46	641	900	400
A. scoparius		59	353	800	200
A. spicatum		67	501	800	200
C. longifolia		11	609	900	400
R. trilobata		10	725	1100	500
A. tridentata		16	1196	1750	700
A. longiseta		6	621	850	400
Y. glauca		5	941	1400	700
S. comata		12	441	600	250
C. nauseosus		5	1683	3300	500
C. viscidiflorus		5	1725	2800	1000
O. hymenoides		4	660	800	500

Table IV-8. COLSTRIP SAMPLES - RAINWATER*
FALL, 1974

F#	Location	pH
2458-A	Hay Coulee	5.41
2459-A	Kluver Home (Wong)	5.46
2460-A	School Section	5.06
2461-A	McRae Home (Wong)	5.33
2462-A	North Pasture	7.06

*Sulfate, conductivity and fluorides have not been tabulated yet.

Because of the strong possibility of more Federal funding (Energy Research and Development Administration) to this laboratory for precipitation chemistry studies in the Colstrip area, a full-time field collector will be assigned to the area during the coming year to secure rain samples. This collector will also obtain rain samples from the NERL sites and our other EPA-designated sites (see list in First Quarterly Report). More data on precipitation chemistry will be generated and recorded in the next NERL progress report.

II. ANNUAL GROWTH INCREMENT, AND NEEDLE AND STEM GROWTH OF PONDEROSA PINE

During the last winter increment, boring was completed at four of the primary study sites. Increment boring of ponderosa pine trees at other sites was not completed because of adverse weather conditions (-20°F) causing increment bores to break during the sample boring process. At the four sites, 12 trees were selected and the circumference (at breast height) and height of each tree was measured. Since the dendrochronometer owned by the U. S. Forest Service, was in constant use by Forest Service personnel during this last winter, no analyses of the increment bores have been completed. However, the Forest Service assures us that the instrument will be available this summer and measurements will be conducted in the near future. Boring will continue this fall on six more ponderosa pine sites. Stem and needle growth studies will be carried out this spring and summer on the four sites bored this past winter.

SUMMARY

It is apparent that my staff has placed heavier emphasis on establishing baseline levels of accumulative phytotoxic substances (sulfur and fluoride) emitted by coal-fired power plants than on other phases of the study.

We believe that it is important to determine the baseline levels of these two elements in vegetation, insects and rainwater prior to the fire-up of Colstrip Unit #1. Then, if and when an impact of emissions does occur on one or more of our study sites, it might be reflected in altered chemical content of some components of the ecosystem.

During the 1975 spring and summer, we plan to have one or two more full-time field collectors to gather samples and data from the Colstrip sites. It is important to collect as much material as possible prior to the fire-up of Unit #1 boiler; this effort will have highest priority in the coming study quarter.

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SECTION V

LICHENS AS PREDICTORS AND INDICATORS OF AIR POLLUTION FROM COAL-FIRED POWER PLANT EMISSIONS

by

Sharon Eversman

INTRODUCTION AND OBJECTIVES

Two lichen species, a terricolous foliose (Parmelia chlorochroa) and a corticolous fruticose (Usnea hirta), are undergoing intensive investigation in this component of the Montana Coal-Fired Power Plant Project. These two lichen species are those most likely to serve as indicators of SO_2 pollution in Southeastern Montana. They are the only species that are abundant enough for use in the evaluation of the physiological and anatomical functions that might signal pollution stress.

Principal objectives are to: (1) establish secure field and laboratory baseline information on these two lichens (Parmelia chlorochroa and Usnea hirta) so that effects of chronic SO_2 challenge may be determined; (2) compare relative sensitivities of lichens, native grasses and ponderosa pine (Pinus ponderosa); and, (3) assess changes in population or community structure that may result from the power plant emissions. Control data were recorded during the summer of 1974 and will continue during the spring of 1975.

To simulate SO_2 pollution similar to that generated by fossil-fuel burning facilities, a Zonal Air Pollution (ZAP) System will regulate sulfur dioxide concentrations on grassland study plots in Southeastern Montana. Responses of plants and animals to this fumigation will be assayed to determine the effects of chronic SO_2 challenge. Then before and after comparisons can be made between their existing condition and conditions after exposure to the fumigation system and power plant emissions. Effects of SO_2 on lichens are expected to serve as sensitive gauges of SO_2 pollution.

The lichen study is designed to detect changes resulting from coal-burning emissions in two major categories--community structure and sublethal biochemical or physiological changes. Data from the lichen study will be correlated with information from the pine forest and grassland communities.

Field Activities

During the late summer of 1974 and spring of 1975, collections were made of lichen species for identification and preparation of a species list from Rosebud and Powder River Counties, Montana. The preliminary list, arranged according to substrate and study area site, is presented in Table V-1. Using the 2x5 dm Daubenmire plots (Taylor, Leininger, and Fuchs, 1974) the researchers attempted to establish the canopy coverage percentage for each species on each grassland study site. Staff estimates were consistently low when compared with Taylor's estimates. During the 1975 field season the activity will be repeated using a camera.

Adequate growth of *Parmelia chlorochroa* and *Usnea hirta* is not indigenous to the Taylor Creek site, so lichen specimens were transplanted to the area. *Parmelia* was collected from a pasture near the site and placed on the bare ground in each of the four fumigation plots. Ponderosa pine branches containing *Usnea* were collected from the divide between Ashland and Lame Deer, Rosebud County; five branches have been wired onto steel fence posts, less than one-half meter above the ground, on each plot. Project staff evaluate the transplants for visible injury, as well as anatomical and physiological changes caused by exposure to

Table V-1. LICHENS COLLECTED SUMMER, 1974

	Hay Coulee	Relict Knolls	Cow Creek	North Pasture	Harvey	Ash Creek	Fort Howes	School Section
Terricolous								
Parmelia chlorochroa	x	x	x	x	x	x	x	x
Cladonia spp.	x		x	x	x	x	x	x
Flugensia fulgens	x		x		x			
Buellia epigaea	x	x						
Collema tenax	x			x	x	x		
Dermatocarpon lachneum	x		x	x	x	x		x
Squamarina lentigera	x				x			
Lecidea decipiens	x				x			
Toninia coeruleonigricans	x							
Acarospora schleicheri	x							
Peltigera canina							x	
Cornicularia muricata					x			
Lignicolous								
Caloplaca aurantiaca			x					
Cyphelium notarsii			x					
Corticolous								
Usnea hirta						x	x	
Hypogymnia physodes						x	x	
Parmelia subolivacea						x		
P. infumata						x		
P. sulcata						x		
P. ulophyllodes						x		
Alectora sp.						x	x	
Cetraria pinastri						x		
Saxicolous or muscicolous								
Parmelia subdecipiens							x	
Physcia caesia							x	

the SO_2 (see subsequent chapter of this report, by Lee, Lewis, and Body).

Laboratory Procedures

The samples of Parmelia and Usnea are washed with distilled water and air-dried for at least 48 hours. The thalli are weighed; some are soaked in acetone for two hours, then reweighed to detect possible deposition of acetone-soluble compounds (Rao and LeBlanc, 1973).

Respiration rates are determined in a Gilson Differential Respirometer; 250-mg samples of entire lichen thalli are moistened for one hour with 1 ml of distilled water. The respiration flask, containing 0.5 cc of 20 percent KOH with a 1.5 x 1.5 cm filter paper wick in the center well, is wrapped in aluminum foil to obtain the dark respiration rate for 2 to 3 hours at 20°C. Figure V-1 shows results from 11 samples from one site. Timing for this procedure has been determined; but many samples are not yet duplicated.

The Analytical Chemistry Laboratory at Montana State University determined the total nitrogen content of one-gram thallus samples, using the Kjeldahl method (Table V-2). Samples from 1975 have not been analyzed. The Soils Testing Laboratory measured total sulfate sulfur content of 1974 (Table V-2).

The chlorophyll absorption spectrum was determined for 1974 samples using the Rao and LeBlanc method (1966). However, this method does not separate chlorophylls a and b, and pheophytins as precisely as desired. A 90 percent acetone extraction method, used in algal chlorophyll analyses, will be employed this year (Strickland and Parsons, 1972). After grinding in 90 percent acetone, the thallus material is centrifuged and the supernatant is sampled in a Beckman DU spectrophotometer.

Figure V-1 Lichen Respiration Rates

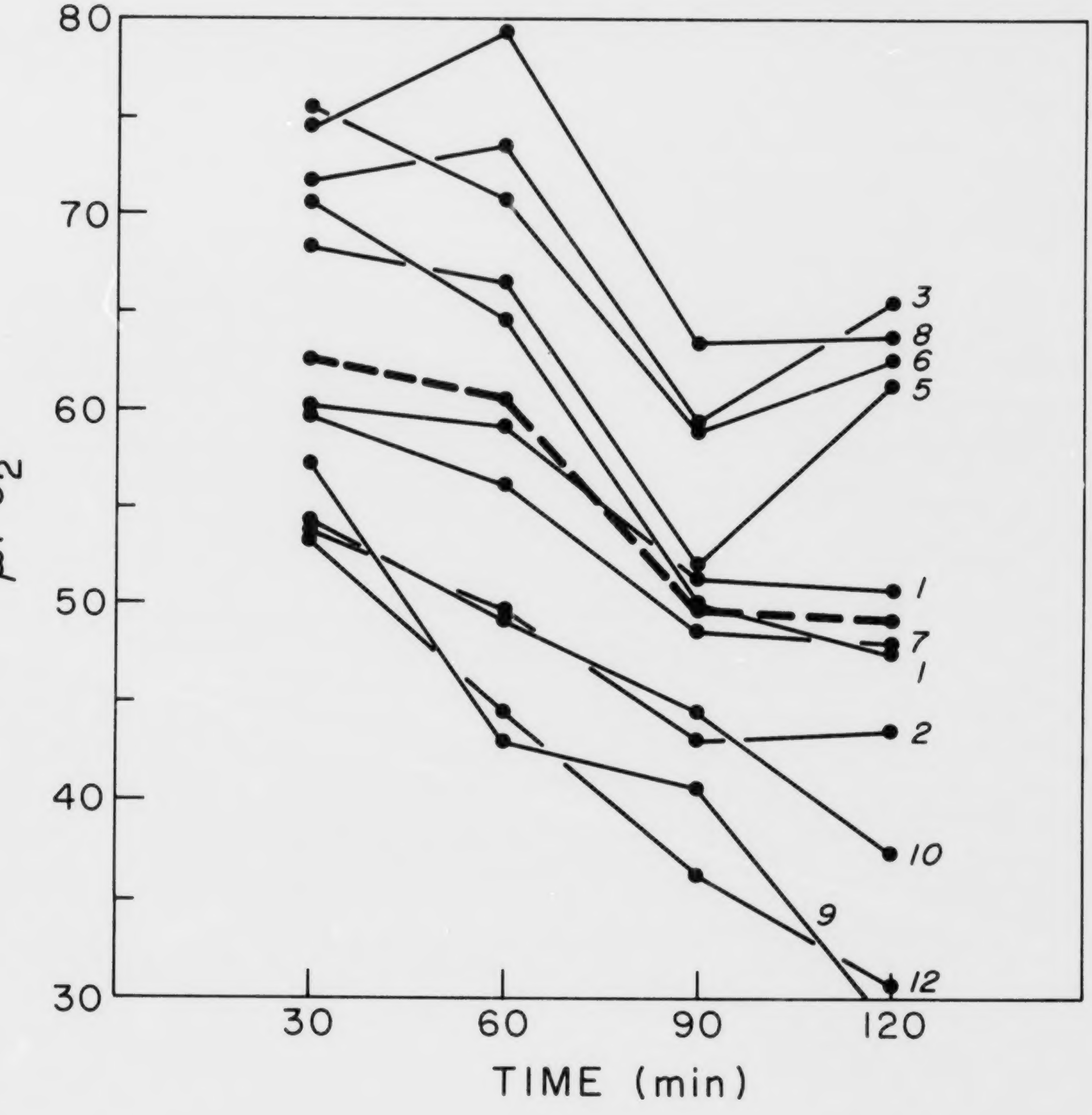

Table V-2. NITROGEN AND SULFUR CONTENTS (%DRY WEIGHT) OF 1974 SAMPLES OF *PARMELIA CHLOROCHROA* AND *USNEA HIRTA*

	% Nitrogen	% Sulfur
Parmelia chlorochroa		
Hay Coulee A	0.72%	0.274
B	0.73	0.248
Cow Creek A	0.82	0.224
B	0.75	0.210
North Pasture	0.73	0.199
School Section	0.77	0.255
Ash Creek A		0.227
Harvey A		0.230
Usnea hirta		
Ash Creek trees	1.52	
Ashland-Lame Deer Divide	1.70	0.442

Project staff feel that these five characteristics--thallus weights, respiration rates, total nitrogen content, total sulfur content, and chlorophyll analyses--along with the field photographs and microphotographs should provide valid bases for comparisons between the unexposed *Parmelia* and *Usnea*, and those samples subjected to the SO_2 on the ZAPS site and in study areas that will be affected by the power plant emissions.

Future Activities

In addition to Usnea and Parmelia collection and laboratory tests, two native grasses and needles from Pinus ponderosa will undergo the same battery of laboratory analyses to determine relative sensitivities of the lichens and the plants in the same plant communities as the Parmelia (grasses) and Usnea (ponderosa pine). If enough specimens of other epiphytic lichens are available, they will be included in the same series of analyses.

Identification of collected species is continuing for characterization of the various lichen communities in the area.

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SECTION VI

PHYSIOLOGICAL RESPONSES OF VEGETATION TO COAL-FIRED POWER PLANT EMISSIONS

by

David T. Tingey, Richard W. Field and Lucia Bard

INTRODUCTION

The objective of this aspect of the research was to conduct preliminary exposures of native plants from Southeastern Montana to sulfur dioxide.

METHODOLOGY

The plants described in Table VI-1 were grown during January 1975 with day/night temperatures of 24/18°C on a photoperiod of 12 hr of light and 12 hr of dark (12L 12D). Maximum light intensity was 200 microeinsteins $m^{-2}sec^{-1}$ at 400-700 nm (1 microeinstein is equal to 6.023×10^{17} photons). The grasses were propagated by division and the Fringed Sage Wort by cuttings. These were planted in 225 ml styrofoam cups containing a 2:1 (v:v) mixture of perlite: Jiffy Mix. Plants for all studies were grown in greenhouses, watered daily with a modified Hoagland solution, and periodically leached with water. Tables VI-2 and VI-3 contain data from plants grown during March and April at day temperatures ranging from 24-30°C, night temperature 18°C, a daily photoperiod of 16L 8D, and light ranging between 350 and 500 microeinsteins $m^{-2}sec^{-1}$.

Table VI-1. THE EFFECT OF SULFUR DIOXIDE ON THE FOLIAR INJURY OF NATIVE PLANT SPECIES[1/]

Species	SO_2 Concentration (ppm)		
	1.0	1.5	2.0
Western Wheat Grass *Agropryon smithii*	5	5	5
Idaho Fescue *Festuca idahoensis*	0	4	13
Prairie June Grass *Koeleria cristata*	0	3	8
Needle and Thread Grass *Stipa comata*	0	4	18
Fringed Sage Wort *Artemisia frigida*	6	31	50

[1/] Plants were exposed for 4 hr; foliar injury was assessed 96 hr following exposure. The injury was assessed as the percentage of the leaf area showing SO_2 injury. Each mean was based on 6 observations, $S_{\bar{x}} = 2$. Exposure conditions were: Temp. = 24°C; light = 200 microeinsteins m^{-2} sec^{-1}.

Table VI-2. THE EFFECT OF SULFUR DIOXIDE ON THE FOLIAR INJURY OF NATIVE GRASSES OF MONTANA[1]

Species	SO_2 Concentration (ppm)			
	0.5	0.75	1.0	1.5
Western Wheat Grass	0	0	0	19
Idaho Fescue	0	0	0	33
Prairie June Grass	0	0	3	16
Needle and Thread Grass	0	0	5	17

[1] Plants were exposed for 4 hr and foliar injury was assessed 96 hr after exposure. The injury was measured as the percentage the leaf area showing SO_2 injury. Each mean was the average of three observations. $S_{\bar{x}} = 3$. Exposure conditions were: Temp. = 26°C; light = 475 microeinstein m^{-2} sec^{-1}.

Table VI-3. SULFUR DIOXIDE INDUCED FOLIAR INJURY OF NATIVE PLANT SPECIES[1/]

Species	SO_2 Concentration (ppm)			
	0.75	1.0	1.25	1.5
Western Wheat Grass	0	0	1	1
Idaho Fescue	0	0	0	3
Prairie June Grass	0	0	0	0
Needle and Thread Grass	0	0	0	0

[1/] Plants were exposed for 4 hr and foliar injury was assessed 96 hr after exposure. The injury was assessed as the percentage of the leaf area showing SO_2 injury. Each mean was based on four observations, $S_{\bar{x}} = 2$. Exposure conditions were: Temp. = 24°C; Light = 360 microeinsteins m^{-1} sec^{-1}.

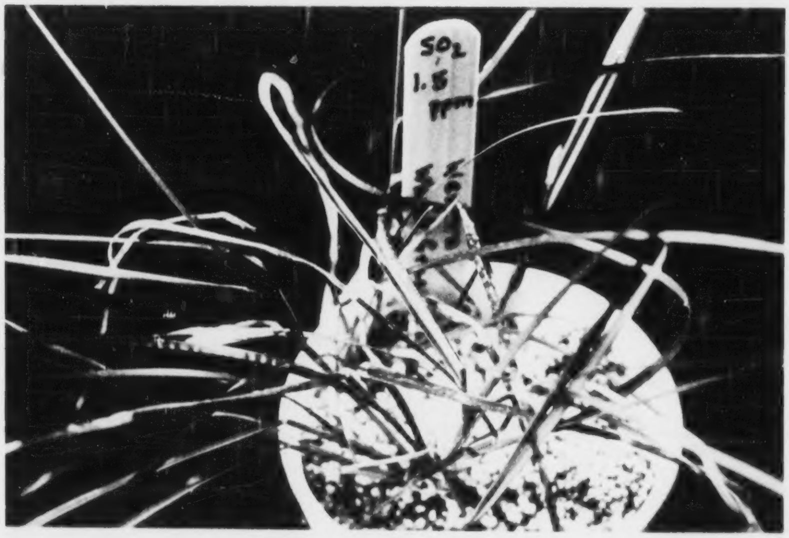
Sulfur dioxide exposures were conducted in single pass exposure chambers (Heck, Dunning, and Johnson, 1968). Sulfur dioxide diluted in nitrogen was metered into the exposure chambers at a rate sufficient to maintain the gas phase concentration. The sulfur dioxide was measured with a Melpar photometric sulfur dioxide analyzer. Prior to each exposure the analyzer was calibrated with a Monitor Lab's dynamic calibrater containing an SO_2 permeation tube. The plants were exposed to sulfur dioxide about four weeks after transplanting. Leaf injury was assessed 96 hr following exposure as the percentage of leaf area showing sulfur dioxide injury. The standard error for leaf injury was calculated; visual estimates of injury do not permit further statisical analysis.

RESULTS

Description of injury (Figures VI-1, VI-2, VI-3). For Western Wheat Grass, Idaho Fescue, Prairie June Grass and Needle and Thread Grass, the sulfur dioxide injury was similar. Injury on young leaves developed at the leaf tip, on older leaves injury usually occurred at the bend of the leaf. Injury frequently occurred as small bifacial lesions. As severity increased the lesions coalesced and spread down the leaf or out from the bend of the leaf. Interval streaks of necrotic tissue were frequent. Lesion color ranged from light tan to ivory. On Fringed Sage Wort the injury appeared to occur on the middle-aged leaf tissue as a bifacial collapse of the tissue, killing both veins and interveinal areas (Figure VI-4).

Relative Sensitivity. The data shown in Table VI-1 for the five species were for plants grown under conditions of low light intensity and relatively cool temperatures. Data in Tables VI-2 and VI-3 were obtained from plants grown under a light regime of 16L 8D--a higher light intensity. This procedure could account for some of the observed differences in sensitivity. Only the Western Wheat Grass and Fringed

Figure VI-1 Western Wheat Grass Exposed to 1.5ppm SO_2 for 4 Hours. The injury is characterized at nectrotic leaf tips and bifacial necrotic lesions at the bend of the leaf.



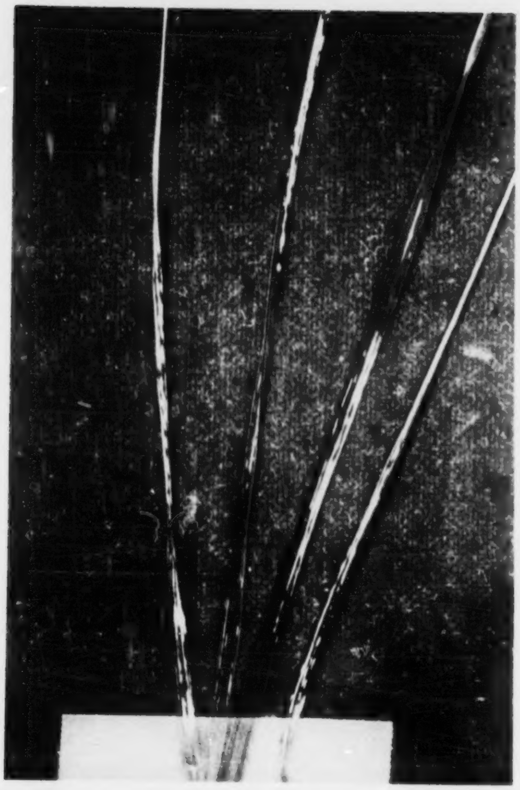


Figure VI-2 Western Wheat Grass Exposed to 1.5ppm SO_2 for 4 Hours. The injury is shown as "bifacial" necrotic lesion between the veins. In places the lesions have coalesced.

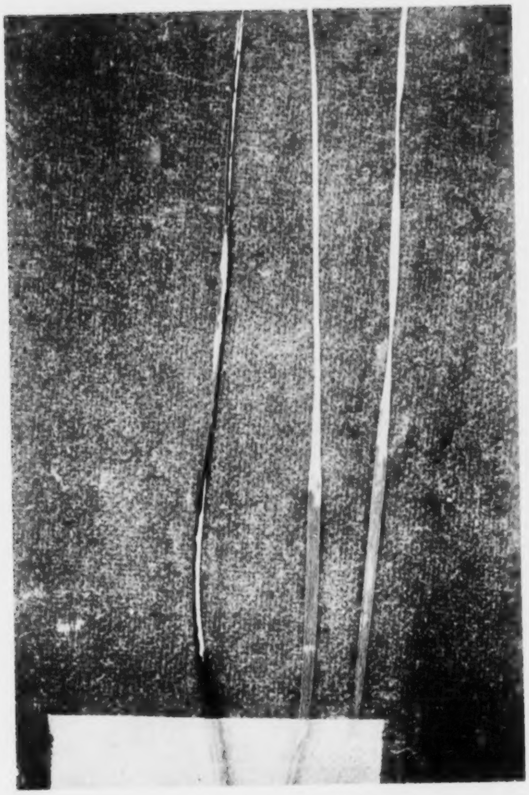


Figure VI-3 Needle and Thread Grass Exposed to 2ppm SO_2 for 4 Hours. The injury symptoms are similar to Figure VI-2.

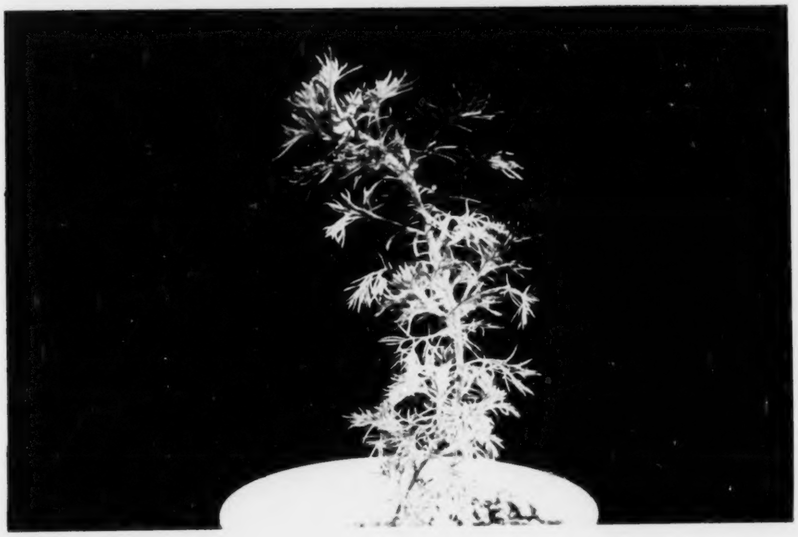


Figure VI-4 Fringed Sage Wort Exposed to 1ppm SO_2 for 4 Hours. The injury is bifacial necrosis of the lower and middle aged leaves of the plant. The injury appears as the lightest color leaf tissue in the photograph.

Sage Wort exhibited injury below 1.5 ppm SO_2 for 4 hr. Data presented in Tables VI-2 and VI-3 indicate there was no injury below 1 ppm for 4 hr. The injury threshold for Western Wheat Grass appeared to range between 1 and 1.25 ppm SO_2. For Idaho Fescue the threshold was approximately 1.5 ppm; for Prairie June Grass and Needle and Thread grass the injury threshold appeared to be between 1 and 1.5 ppm. Based on limited data, the threshold for Fringed Sage Wort was approximately 1 to 1.25 ppm.

In general, available data suggest that Western Wheat Grass and Fringed Sage Wort are somewhat more sensitive than the other three species tested.

DISCUSSION

The injury observed on the native species was similar to that previously described (Barrett and Benedict 1970; Hill, Hill, Lamb, and Barrett, 1974). Injury thresholds suggested for the species tested in our experiments do not take into account the effect of soil water potential on plant sensitivity. Low soil water potential could reduce plant sensitivity.

Davis, Howell, and Morgan (1966) reported that levels of sulfur dioxide that might be expected around Phelps Dodge smelters in Arizona, and which would defoliate cocklebur, did not injure blue gramma. Hill et al. (1974), working with established native plants in the field, showed that species of *Agropyron caninun* and *A. desertorum* required between 6 and 10 ppm SO_2 for 2 hr to cause visual injury. This suggests that these two species of Wheat Grass are more tolerant of SO_2 than Western Wheat Grass. Hill watered the plants for a month prior to exposure to ensure that they were in a stage of rapid growth and thus highly sensitive. He also reported that *Stipa occidentalis* required 10 ppm SO_2 for 2 hr to induce visual injury. This suggests that *Stipa occidentalis* is more tolerant than *Stipa comata* which showed injury of both 1.5 and 2 ppm SO_2 for 4 hr.

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SECTION VII

INVESTIGATION OF THE EFFECTS OF COAL-FIRED POWER PLANT EMISSIONS UPON INSECTS, REPORT OF PROGRESS

by

Jerry J. Bromenshenk

INTRODUCTION

This section discusses the progress on the insect studies subsequent to the First Interim Report of December, 1974 (National Ecological Research Laboratory, 1975). The objectives referred to below correspond to those elaborated by C. C. Gordon in a preceding chapter of this report.

OBJECTIVE #1

Field surveys of insect populations, infestations, and damage to indigenous plant species at the study sites were initiated on August 1, 1974. They were terminated in late October, 1974, and resumed in mid-May, 1975. Initiation of the 1975 field work coincided with the appearance of those insect species considered to be most important, both to the goals of this study and to the ecosystems of Eastern Montana. Selection of species for individual study was based on (1) insect surveys performed in 1974; (2) plant samples that were collected during this same period and subsequently examined for insects and damage; and (3) an intensive review of the literature concerning insects and air pollution relations. Handling of plant and insect samples, survey methods and analyses are discussed in an earlier report (Gordon, 1975).

This phase of the project utilizes all of the principal study sites, together with the 14 sites described in an earlier chapter of this report by C. C. Gordon as well as 15 apiaries (Figure VII-1). Four additional apiaries are being sampled: one near the town of Rosebud to the north, one near Broadus to the east, one at Fort Howes Ranger Station to the south, and one near Biddle to the southeast. Since the Colorado State University research group is sampling vegetation and insects on the NERL sites, this phase is concentrating on the other sites to avoid redundancy. However, I have examined the primary sites and am monitoring population trends of the western harvester ant, _Pogonomyrmex_ spp. Honeybees will be used in experiments at the field experimental site on Taylor Creek (see the chapter of this report by Lee, Lewis and Body).

Insect pests of ponderosa pine constitute a major insect-plant system of ecologic and economic importance to the Colstrip area. Population and damage studies begun in August, 1974, revealed several types of insect damage to needles, cones, and woody portions of the pines. Statistical analyses of the damage sustained by foliage are based on samples of 100 needles per tree for each year of growth. Cone damage is computed as the percent total cones damaged per tree as indicated by the cones on the branch samples. The materials and methods for this work follow those of Carlson, Bousfield and McGregor, (1974).

Insect damage to most of the trees was slight or low. At some sites, many or all of the cones were damaged by larvae of cone beetles (_Conophthorus_ spp.) and cone moths (_Laspeyresia_ spp. and _Dioryctria_ spp.). Tree vigor (damage) ratings and cone injury data are presented in Table VII-1. Insects that attack cones reduce or destroy seed crops but usually do not seriously harm the trees. High variability of the cone injury data indicated that the sample size was probably not adequate for establishing baseline damage levels. Similar difficulties with variability occurred with evaluations of damage by other species of

Figure VII-1 Honeybee Collection Sites.

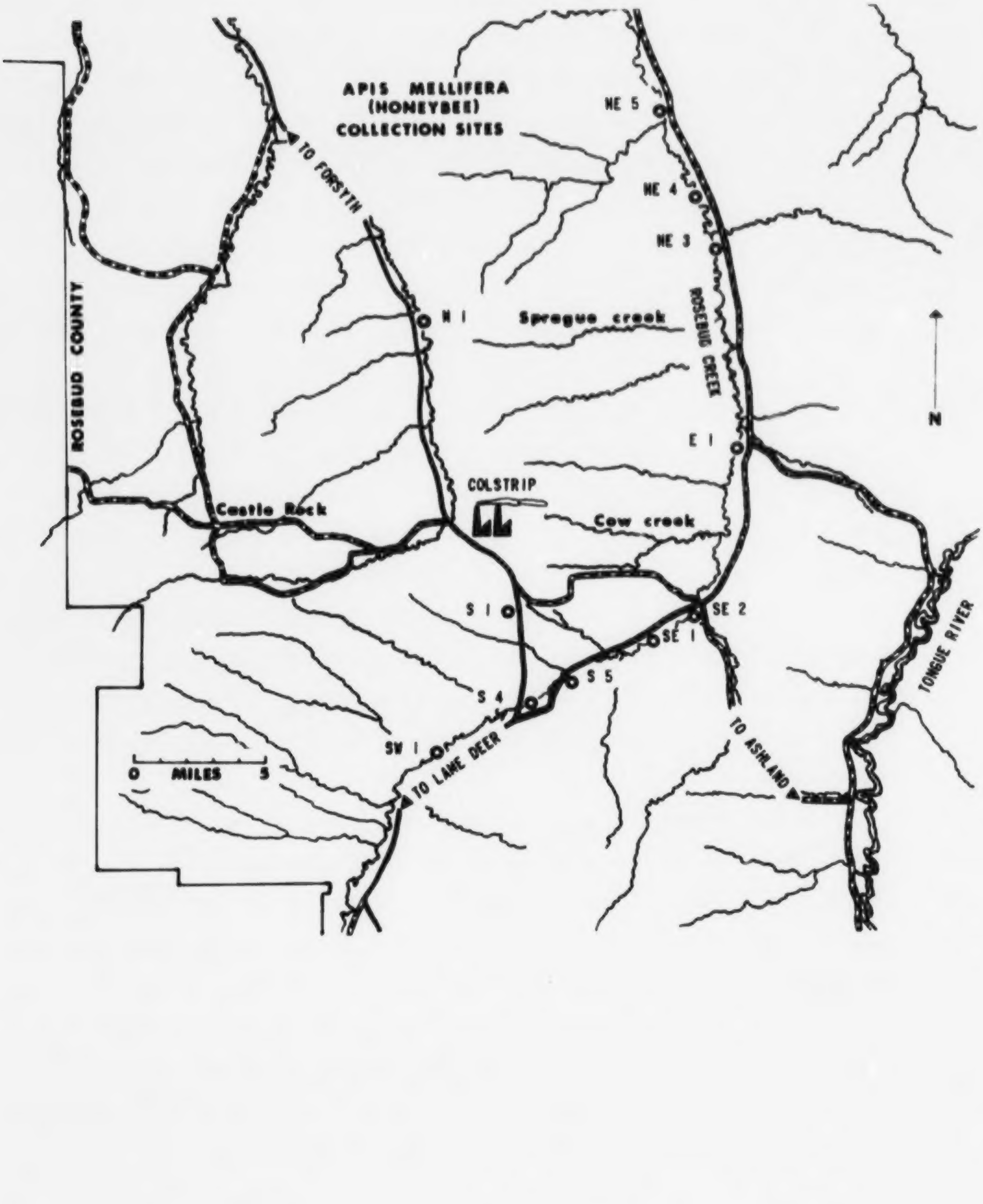
APIS MELLIFERA
(HONEYBEE)
COLLECTION SITES
NE 5
TO FORSYTH
NE 4
NE 3
N 1
Sprague creek
ROSEBUD CREEK
ROSEBUD COUNTY
N
E 1
COLSTRIP
Castle Rock
Cow creek
S 1
SE 2
SE 1
S 5
S 4
SW 1
0 MILES 5
TO LAME DEER
TO ASHLAND
TONGUE RIVER

Table VII-1. INSECT DAMAGE TO PONDEROSA PINES AT 13 SITES
TREE DAMAGE AND CONE DAMAGE
(Preliminary data, subject to revision and possible enlargement of data base before 1975 growth)

Tree #	Site	Tree Damage (0 low - 4 high)	Per Cent Total Cones Damaged (Cone beetles and Cone Meths)
		$\bar{X}$ = .08 SD = .27	$\bar{X}$ = 33.35 SD = 30.65
F1495	SE-1	0	61
F1490	"	0	40
F1485	"	0	88
F1480	"	0	68
F1475	:	0	0
F1050	SE-3	0	6
F1055	"	-	0
F1060	"	0	27
F1065	"	0	0
F1070	"	0	0
F1770	W-3	0	50
F1765	"	0	57
F1760	"	0	40
F1755	"	0	43
F1750	"	0	8
F1200	W-4	0	0
F1205	"	0	14
F1210	"	0	11
F1215	"	0	22
F1220	"	0	5
F1300	N-4	0	5
F1305	"	0	0
F1310	"	0	46
F1315	"	0	7
F1320	"	0	33

Table VII-1 (Continued)

Tree #	Site	Tree Damage (0 low - 4 high)	Per Cent Total Cones Damaged (Cone beetles) and Cone Moths)
F1575	NE-3	0	40
F1580	"	0	83
F1585	"	0	0
F1590	"	0	0
F1595	"	0	43
F1850	NE-1	0	19
F1855	"	0	19
F1860	"	0	78
F1865	"	0	8
F1870	"	0	24
F1825	E-1	0	8
F1830	"	0	56
F1835	"	0	64
F1840	"	0	46
F1845	"	0	17
F1275	E-3	0	21
F1280	"	0	0
F1285	"	0	100
F1290	"	0	16
F1295	"	0	--
F1250	E-4	0	11
F1255	"	0	0
F1260	"	0	0
F1265	"	0	6
F1270	"	0	0
F1225	"	0	--
F1230	"	0	6
F1235	"	0	26

Table VII-1 (Continued)

Tree #	Site	Tree Damage (0 low - 4 high)	Per Cent Total Cones Damaged (Cone beetles and Cone Moths)
F1240	NW-3	0	87
F1780	"	0	79
F1785	"	0	92
F1790	"	0	75
F1795	"	0	42
F1350	NW-4	1	83
F1355	"	1	50
F1360	"	1	46
F1365	"	1	--
F1370	"	0	100

insects such as weevils that attack the needles, although to a lesser extent. However, for most insect damage, such as that incurred from scale insects, needle and sheath miners, defoliators, and bark beetles, and for the tree vigor (damage) evaluations, the sample size appeared to be adequate.

Many types of injury are characteristic of a particular species or at least a family of insects. Since the samples were obtained in the fall of 1974, many of the damaging insects were no longer visible on the plants. Confirmation of the identification of the specific insects responsible for the damage must be made at the time insects are feeding. Completion of the baseline insect populations and damage of ponderosa pines relies on surveys and collections to be conducted this spring and summer. This work started in May. The number of treees sampled per site has been doubled to minimize variability due to sampling error. The sites will be visited several times during the field season to observe the insect populations while injury is occurring, and preliminary analyses of injury will be conducted at the sites rather than in the laboratory to avoid damaged artifacts such as chlorosis of needles caused by storage.

OBJECTIVE #2

Plant-insect systems which have a diversified but understandable interrelationship were selected on the basis of the survey work and literature review described in Objective #1. The systems selected for more intensive investigations are listed in Table VII-2. These are concerned primarily with pests of ponderosa pines and with beneficial insects, mainly pollinators.

Damage syndromes caused by insects such as some scales, aphids, weevils, needle midges, and "mites" may resemble that of air pollution

Table VII-2. INSECT SPECIES SELECTED FOR STUDY

Pollinators	
Apis mellifera L.	Honeybee
Bombus spp.	Bumblebee
Nomia melanderi	Alkali bee
Osmia spp.	Leaf-cutter bee
Forest Pests	
Neophasia menapia Felder & Felder	Pine butterfly
Phaeoura mexicanara (Grote)	Pine looper
Ips pini (Say)	Pine engraver
Ips calligraphus (Germar)	Pine engraver
Dendroctonous valens Lectone	Red turpentine beetle
Dendroctonous ponderosae Hopk.	Mountain pine beetle
Eucosma spp.	Pine-shoot borer
Rhyacionia spp.	Shoot and tip moths
Cicididae	Cicadas
Buprestidae	Flatheaded borers
Itonididae	Gall midges
Cerambycidae	Roundheaded borers
Dioryctria spp.	Coneworm
Laspeyrsia spp.	Cone or nut moth
Phenacaspis pinifoliae (Fitch)	Pine-needle sacle
Conophthorus Hopk.	Cone beetles
Curculionidae	Weevils
Miscellaneous insects	
Melanoplus spp.	Grasshoppers
Pogonomyrmex spp.	Harvester ant

but can be differentiated by dissection and histological examinations (Anderson, 1970). Specimens of insect damage to pine needles have been prepared for histological sectioning using formaldehyde-ethanol-acetic acid fixation as described in an earlier section of this report by C. C. Gordon. Histological investigations are in progress and should help us to distinguish insect damage from other types of damage such as that produced by pollution or fungi. C. C. Gordon is conducting histological studies of fungal parasites and host plant species. Previously he conducted histological studies of several types of air pollution damage to pine needles.

OBJECTIVE #3

Selection and pre-testing of insects for inoculation studies of injury-causing insect species were conducted during the winter. A laboratory population of _Malanoplus bivittatus_, a grasshopper species, was established (Figure VII-2). Methods of rearing various pine pests in the laboratory were investigated and tested. In general, rearing of pine insects depends on providing the insect with its preferred food such as boughs of foliage for needle damaging insects and bolts of wood for bark beetles. Use of synthetic diets was considered unrealistic in terms of the objectives of the present study. We are currently rearing several species of pine pests in the laboratory, including the pine needle scale, _Phenacaspis pinifoliae_ (Fitch); weevils, _Pissodes_ spp.; needle midges, _Contarinia_ spp.; and bark beetles _Ips_ spp. and _Dendroctonus_ spp. (Figure VII-3). These insect populations will be used in laboratory fumigation experiments as soon as adequate numbers have been established--sometime this summer. I shall continue to collect insects for laboratory rearing.

Figure VII-2 Laboratory Population of Malanoplus bivittatus.

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best available copy.

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best available copy.

Phenacaspis pinifoliae (Fitch)
Pine Needle Scale
F 602 A

Figure VII-3 Laboratory Colonies of Various Pine Pests.

OBJECTIVE #4

The selection and pretesting of beneficial insect species to be used at study sites and in the laboratory has primarily involved honeybees. Approximately 3,000 honeybee colonies are maintained in the Fort Union Basin. Each October 1,000 colonies are transported to California to pollinate orchard crops; the colonies are returned in May. The bees and bee products from this region, at a conservative estimate, comprise a \$240,000 to \$300,000 enterprise. According to Floyd Moeller, research leader of the North Central States Bee Laboratory, the actual value of honeybees as pollinators may be more than twenty times that of the honey product. This means that the honeybees in Southeastern Montana may be worth \$4.5 million as pollinators of rangelands and agricultural lands and an additional \$500,000 to \$1 million as pollinators of California crops. (Data based on marketable honey yields from 1,200 colonies in the Fort Union Basin, confidential report.) In addition to honeybees, native bees are plentiful and may be capable of meeting the pollination needs of the Fort Union area. However, evidence indicates that the native bees, especially the physically smaller species, may be much more susceptible to pollutant toxicosis than honeybees (Johansen, 1971).

Manageability and the numbers of honeybees in the study area make them an excellent subject for study. Hopefully, they will be indicative of the population trends of other pollinators. Native bees such as leaf-cutter bees, wild honeybees and bumblebees will be used for comparative studies.

Field experiments are now in progress to evaluate physiological and behavioral responses of honeybees to controlled exposures of sulfur dioxide (see Lee, Lewis and Body, present report). Two colonies (50-100,000 bees per colony) have been established near the SO_2 stressing plots. In addition, two observation hives (Figure VII-4) will be used

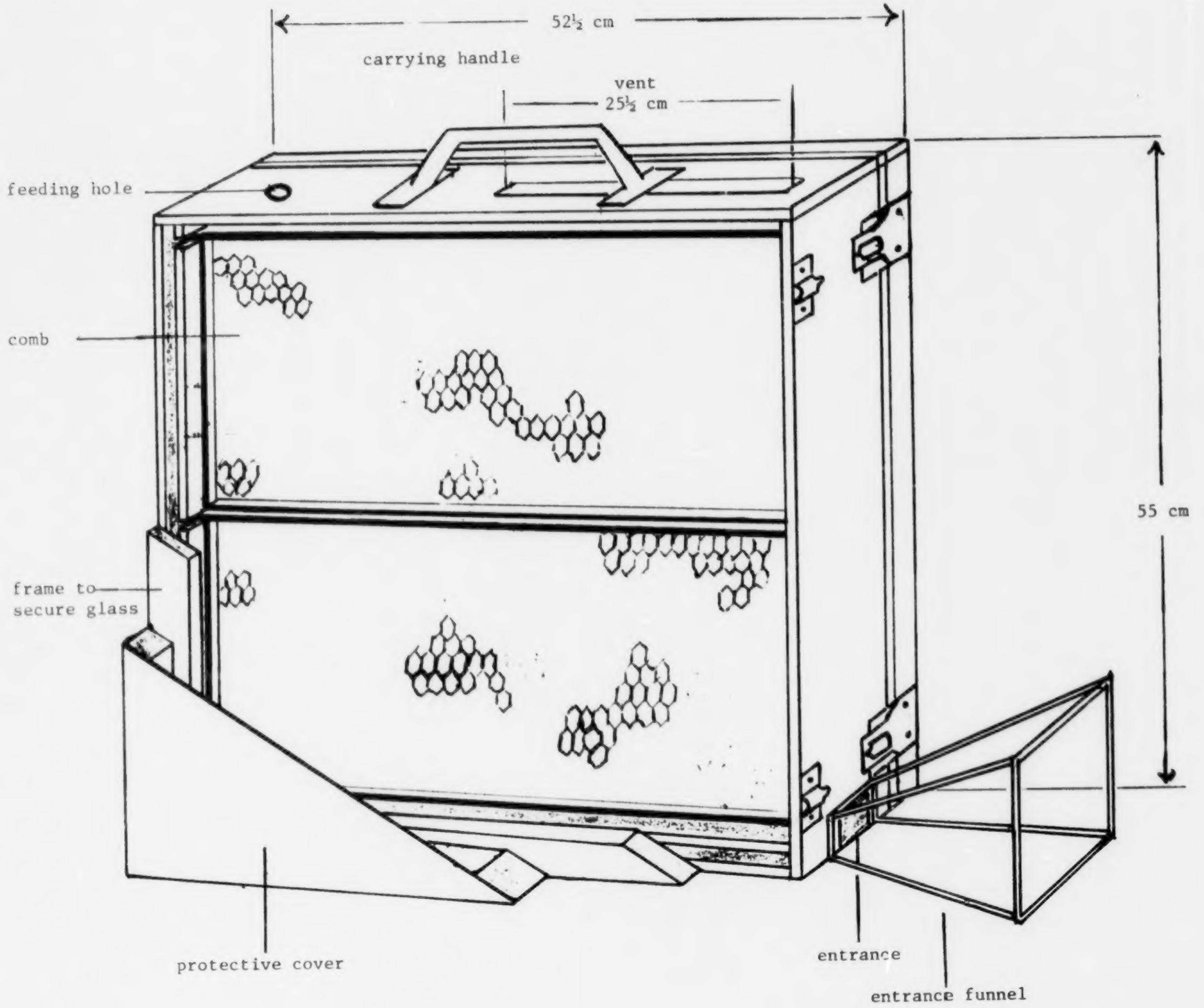

52½ cm
carrying handle
vent
25½ cm
feeding hole
comb
frame to secure glass
55 cm
protective cover
entrance
entrance funnel

Figure VII-4 Glass-walled Observation Hive.

to monitor the activities of bees within hives. I am particularly interested in dance patterns which may be altered by sublethal exposures to pollutants. The glass-walled observation hives are readily movable and may be used in a variety of positions such as up, down or cross-wind directions; near or far from the plots; and possibly on the plots. Feeding stations will be established on the plots, primarily to determine if differing visitation patterns occur in response to the SO_2 emissions.

A ferrous-metal tag capture-recapture technique (Gary, 1971) will be applied where appropriate for distribution, movement and flight range studies of bees. Coded metal tags are glued to the bee's abdomen. Later, these labels are retrieved using magnets at strategic locations. The system was tested this spring and appears to work well. For example, tags from honeybees marked at feeding stations could be retrieved at hive entrances. If bees are tagged as they leave the hive, the tags will be retrieved at the first collection point visited by the foraging bees. Total counts of bees visiting specific locations may be estimated by this method. However, either direct observations or some means of mechanically counting bees such as by a photo-cell must be utilized for inclusive counts. The proposed budget for the next fiscal year has requested funds to construct some photo-cell counters. For the current season, direct observation and counts that can be made by walking a transect will be used.

A possible source of physiological and behavioral variability is the genetic composition of the bee populations that are under investigation. To minimize data variations resulting from genetic differences, the colonies at the ZAP plots will be stocked with queens of similar genetic constitution. These queens will convert the colonies to the "same" genetic composition. Queens have been received from the U. S. Department of Agriculture Bee Breeding and Stock Center of Baton Rouge, Louisiana. Two-way sister hybrid queens artificially inseminated with sperm from drones of a single inbred line were obtained in mid-May, 1974, and introduced into eight colonies near Broadus, Montana. These colonies will be used to stock the hives at the ZAP plots as soon as the queens have become well established and the colony has reached a healthy, vigorous condition.

OBJECTIVE #5

Chemical analyses of indigenous plants and insects which were selected for investigation and sampled in the fall of 1974 were completed during the winter, 1974. Dr. Gordon has reported methods and results of the vegetation analyses in a preceding chapter. Honeybees were sampled in October and again in mid-May and will be sampled twice this season for chemical analyses.

Adult honeybees were collected with an electric vacuum apparatus from 11 apiaries in October and from three apiaries in mid-May (most of the colonies were too weak from overwintering to test until June). Three one-pound honey jars filled with bees were obtained from each apiary. Each sample contained specimens from at least four colonies and held from 500 to 15,000 bees. The specimens collected in October were analyzed for fluoride and sulfur; the results are presented in Table VII-3. The assays demonstrated a mean fluoride (F^-) content of 7.4 ppm dry weight and a standard deviation of 3.1 (Table VII-3). Concern has been expressed by other investigators that the levels of F^- in the bees varied three-fold among the sites; however, the content of F^- in the honeybees from the Fort Union Basin appears reasonable as a baseline figure. Carlson and Dewey (1971) reported 10.5 ppm F^- in bees from a control "clean" area in Northwestern Montana, while bees collected near an aluminum reduction facility at Columbia Falls, Montana, contained 221 ppm F^-.

Table VII-3

CHEMICAL ANALYSES OF ADULT HONEYBEES (APIS MELLIFERA)--AUTUMN, 1974

Distance (Miles) & Direction From Colstrip	ppm Fluoride (dry weight)
6.8 N	4.8, 5.6
17.0 NE	7.8, 6.6
15.0 NE	5.5, 5.5
14.5 NE	15.5, 15.8
11.4 E	6.4, 5.5
8.8 SE	10.1, 8.0
4.2 S	5.2, 5.0
4.2 S	5.8, 7.5
8.8 S	11.2, 10.8
8.0 S	5.9, 6.2
10.0 S	6.7, 7.2
12.0 SW	5.5, 5.0

$\bar{X}$ = 7.4
SD = 3.1

CHEMICAL ANALYSES OF ADULT HONEYBEES (APIS MELLIFERA)--AUTUMN, 1974

Distance (Miles) & Direction From Colstrip	ppm Sulfur (Dry Weight)
6.8 N	4400, 4800
17.0 NE	4600, 4800
15.0 NE	4000, 3800
14.5 NE	4200, 4400
11.4 E	4000, 4400
8.8 SE	4800, 4600
4.2 S	4400, 4800
4.2 S (C)	4400, 4400
8.8 S	4600, 4600
8.0 S	4200, 4400
10.0 S	4400, 4400
12.0 SW	4000, 4000

$\bar{X}$ = 4392
SD = 286

The literature indicates that honeybees rapidly accumulate fluoride (Figure VII-5). Maurixio (1955-56) found that dead honeybees obtained from apiaries near industrial areas contained 50-1120 ppm F$^-$, while control bees contained 040 ppm F$^-$. Dreher (1965) suggested 10 μg per bee as the average threshold of toxicity. Note that the baseline levels of F$^-$ in plants reported earlier in this report indicate that a three-fold difference within and between species of vegetation is not uncommon. Bees also must obtain water for drinking. Thus, because of their mobility, utilization of different plant species, and possible contact with fluoride in water as well as respiratory intake, bees from different locations would be expected to have differing fluoride levels. However, the F$^-$ content of bees from Eastern Montana should be relatively low in comparison to that of bees in polluted areas. At present the Fort Union area is relatively free of air pollution.

Fluoride uptake in honeybees may occur through (a) pollen, (b) water, (c) nectar, (d) honeydew, (e) bee products (honey and wax), and possibly (f) respiration. Water does not appear to be a major source of fluoride in the study area. Well and surface waters in the Colstrip vicinity contain 0-0.5 ppm F$^-$, with a mean of approximately 0.2 ppm F$^-$ (unpublished data, Bureau of Mines and Geology, personal communication by Robert B. Hedges). Pollen, honey, live bees, and dead bees will be collected and chemically analyzed to monitor the environmental routes of F$^-$ transport into bees. While nectar and honeydew may be sources of F$^-$, efficient methods of collecting these materials have not been identified, although it is possible to analyze entire flowers. Pollen will be collected this summer using pollen traps--wire grids placed in front of hive entrances. Bees must enter the hive by squeezing through the wires which brush pollen from the "pollen baskets" into jars or trays below the grids (Figure VII-6).

Figure VII-5 Accumulation of Fluorides in Tissues of Adult Honeybees Near Industrial Areas, as Reported by Guilhon (11).

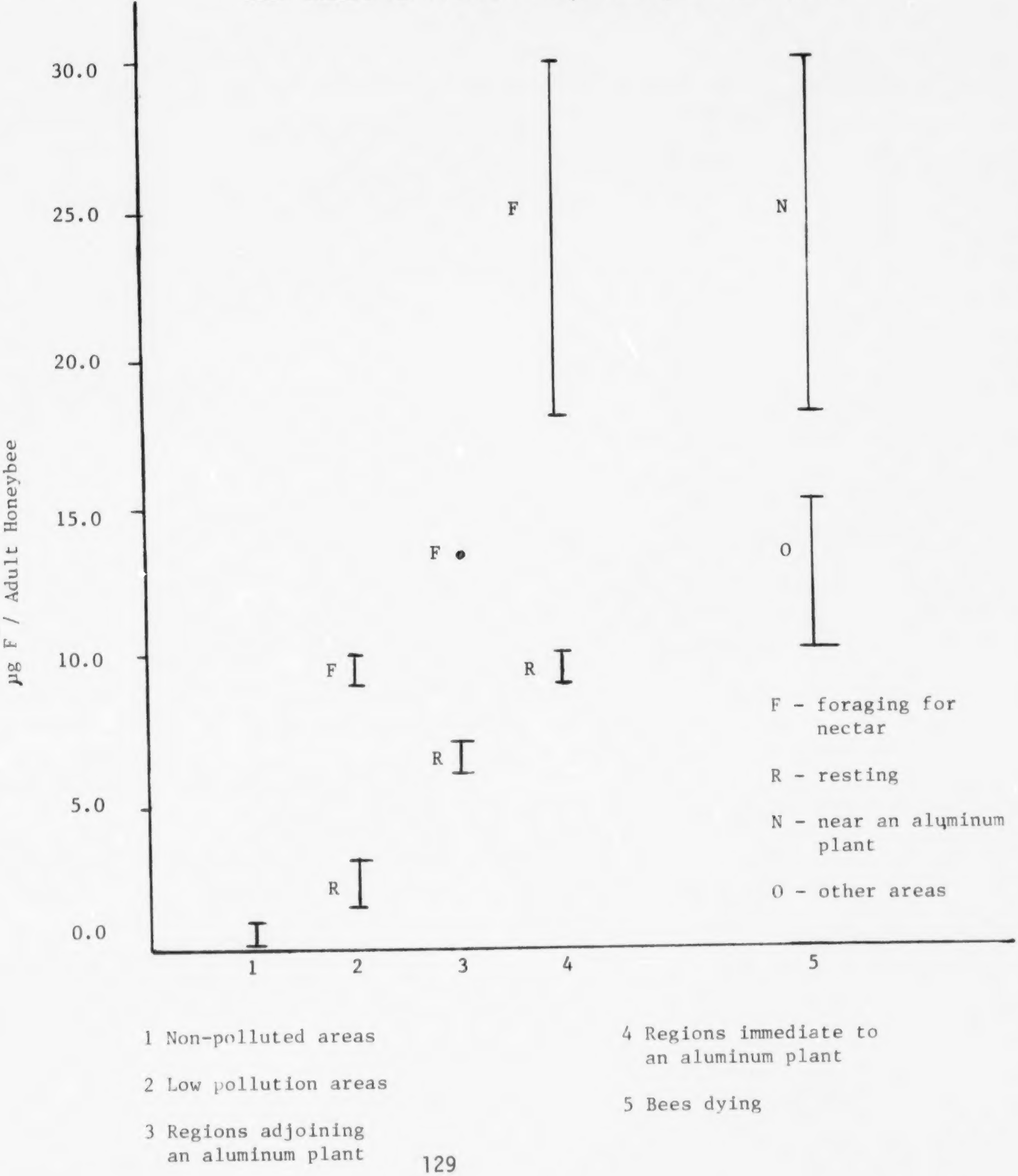
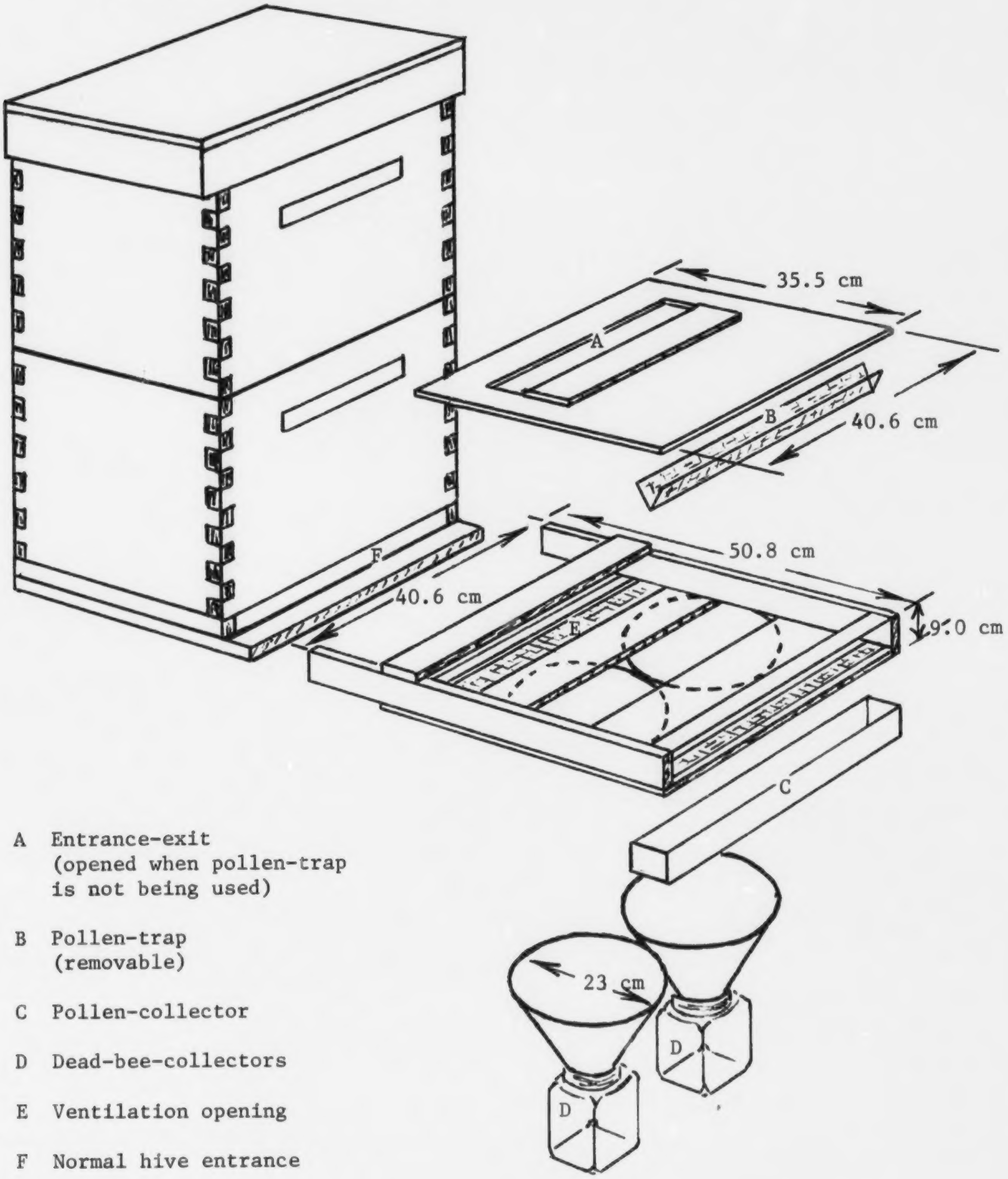


Figure VII-6 Pollen Trap.


35.5 cm
A
B
40.6 cm
50.8 cm
F
40.6 cm
E
9.0 cm
C
23 cm
D
D

A Entrance-exit (opened when pollen-trap is not being used)

B Pollen-trap (removable)

C Pollen-collector

D Dead-bee-collectors

E Ventilation opening

F Normal hive entrance

An electric vacuum has proven to be the most effective method of collecting live bees, while a dead-bee trap (Figure VII-6) will be used to capture "abnormal" or dead bees. An open-ended box is fitted over the hive entrance. Honeybees entering or leaving the hive are forced to walk across the floor of this box. Two 9" funnels attached to pint jars are set flush into the floor of the apparatus. Housecleaning bees remove debris or dead or abnormal bees from hives. Light debris is carried away by flight and dropped at a distance away from the hive. The funnels of the dead-bee-trap are an impassable barrier. Either the housecleaning bee will drop its burden into the funnel, or the bee and its load will slide down the funnel into the jars, whereupon the live bee flies back out. The smooth surface of the funnels and the jars prevent the housecleaning bees from emptying the bottles. Bees that die away from the hive cannot be collected with the dead-bee-trap, but data for studies such as quantitative mortality chemical analyses, and disease investigations may be obtained with a minimum expenditure of time and labor by the researcher.

Bee products such as honey and wax are easily obtained from the hives for analyses. These products may be an important source of re-introduction of contaminants since the stored food reserves are ingested. Honeybees from the Colstrip Area are transported to California each winter and returned to Montana in the spring. The stored reserves of these colonies may contain any number of pollutants. For this reason, 36 hives will be left at six sites in Eastern Montana for sampling purposes.

Sulfur analyses (Table VII-3) demonstrated a mean of 4,392 ppm dry weight and a standard deviation of 286. Sulfur occurs as a natural portion of animal tissue and there appears to be a question of whether or not it accumulates, although exposure to SO_2 at 8.2 ppm for three weeks increased the sulfate in honeybee haemolymph by a significant amount (Gunnison, 1970). Currently, the information contained in the literature about sulfur in bees is inadequate and conflicting. Sulfur analyses will be conducted on bees, bee products and forage materials as indicated above for fluorides. Sulfur may affect acetylcholinesterase levels in bees. Therefore, Robert A. Lewis, animal physiologist, intends to conduct acetylcholinesterase analyses on bee tissue. One of the three samples from each apiary has been sent to Robert A. Lewis. This work is not yet complete.

Last summer, 700-800 bee colonies died from pesticide poisoning in the Fort Union Basin. Pesticides may be a serious, confounding factor. In cooperation with this project, Ronald Thomas of the EPA Biological Investigations Laboratory is conducting pesticide analyses of bees. The third sample taken from each apiary is sent to him. The results of the pesticide analyses of the bees collected in October are presented in Table VII-4. Bees from seven sites contained residues of organochlorine-type pesticides, although no carbamates or organophosphate pesticides were found in any of the samples. The levels of pesticides detected were low. The analytical methodology used in the analyses of these samples were those outlined in the FDA Analytical Manual for chlorinated insecticides (e.g., DDT, DDE), phosphate pesticides (e.g., malathion, parathion), and carbamate pesticides (e.g., sevin, carbofuran). All of the methods used were sensitive to approximately 0.01 ppm. Screening procedures utilized gas chromatography, thin layer chromatography, and gas chromatography in conjunction with mass spectrometry.

Studies of the toxicity of industrial pollutants to bees often present contaminant content as a unit of mass or weight per one bee rather than per unit of mass or weight of bee tissue. Therefore, wet and dry weights of bees obtained from Colstrip are presented in Table VII-5 so that a comparison can be made to other reports.

Table VII-4. HONEYBEE SAMPLES CONTAINING RESIDUES OF ORGANOCHLORINE-TYPE PESTICIDES*

BSE-1 A-1	0.02 ppm DDE
BNE-3 A-1	Trace DDE (<0.01 ppm)
SE-1 A-1C	0.02 ppm DDE/DDD
BE-1 A-1	Trace DDE (<0.01 ppm)
BS-1 A-1	0.02 ppm DDE
BSW-1 A-1	0.025 ppm DDE
BNE-5 A-1	0.01 ppm DDE

*Source: U. S. EPA, TSD-Chemical and Biological Investigations Laboratory, Beltsville, Maryland

Table VII-5. WEIGHTS OF ADULT WORKER HONEYBEES (APIS MELLIFERA)

F#	gm wet weight/ 500 frozen bees	grm wet weight/ bee	gm dry weight/ 500 oven-dried bees	gm dry weight/ bee
2403-A	45.253	0.091	14.999	0.030
2404-A	43.434	0.087	14.029	0.028
2405-A	42.856	0.086	14.037	0.028
2406-A	46.065	0.092	16.263	0.033
2407-A	48.609	0.097	15.351	0.031
2408-A	48.582	0.097	17.544	0.035
2409-A	47.291	0.095	15.290	0.031
2410-A	45.903	0.092	14.273	0.029
2411-A	46.589	0.093	15.665	0.031
2412-A	46.275	0.093	15.061	0.030
		$\bar{X}$ = 0.092		$\bar{X}$ = 0.031
		S = 0.004		S = 0.002

Emphasis of this aspect of the Montana project will continue to be placed on baseline levels of accumulative toxic substances (sulfur and fluorides) in vegetation and insects prior to the shake-down operations of the Colstrip power plants. Also, efforts have been made to establish baseline levels of insect damage to ponderosa pine, one of the more susceptible plants to phytotoxic air pollutants, and for which there is evidence that insect infestations may correlate with physiological weakening of the trees due to air pollution (Carlson, Bousfield and McGregor, 1974). It is also possible that predators and parasites of these pine pests may be reduced in numbers or eliminated by toxicosis. Finally, emphasis has been placed on work with honeybees, an insect that because of its morphological and behavioral specialization for foraging widely and collecting pollen and other particulates, may be one of the insects most sensitive to pollution effects.

During the spring and summer of 1975, the high priority objectives will be to collect as much baseline data as possible from the Colstrip sites before the power plants begin operation.

The insect studies should contribute to an understanding of the plant-insect-fungal relations of both the grassland and forest ecosystems of Southeastern Montana. The information about responses of pollinators to air pollution stress should be invaluable to the other studies being conducted on plant diversity, plant productivity, and energy flow relations. The Colorado research group has concentrated on inventories of the insect and other arthropod fauna and on consumer, producer, and decomposer relations. This study contributes information about insect population trends, behavior, and physiology, as well as following pathways of air pollutants through an insect system: honeybees. In addition, our work with the pine forest ecosystems contributes to an area not being investigated by any of the other research groups, yet is a prominent component of the Eastern Montana ecosystems.

While conducting research and development activities during the winter months, 1974-75, it became apparent that insect systems are very sensitive to pollution stress and respond in diverse ways. For example, some insect populations increase while others decrease or disappear. Insects appear to be valuable indicators of environmental quality. Economically and ecologically, insects have a great impact on a region. Pollinators, primarily because of pesticide poisoning, but also because of other toxic pollutants, are in short supply in many areas of the United States. This affects not only the natural ecosystems, but also vital food supplies. California orchard and produce growers import bees from Montana and North Dakota to meet their minimum pollination requirements. Yet honeybees cannot replace native pollinators. For example, 37 species of native insects are capable of pollinating onions, but honeybees are not very effective (telephone conversation, March 14, 1975, Dr. Frank D. Parker, USDA, Bee Biology and Systematics Laboratory, Logan, Utah). Approximately one-third of the total United States diet is derived, directly or indirectly from insect pollinated crops (McGregor, 1973).

At workshop sessions of the Western Institute of Forest Insect and Disease held in Monterey, California, March, 1975, interactions of air pollution, insects, and disease on forest ecosystems repeatedly were discussed, particuarly regarding problems in California and Northwestern Montana. Unfortunately, adequate information concerning these problems is lacking.

Telephone interviews conducted during the winter indicate the research projects concerning insects and pollution in the United States except for the NERL project are almost non-existent. Studies must be initiated to clarify the relationships of insects and air pollution. A bibliography of the literature concerning air pollution and insect pollinators has been included for use by other investigators (see

Appendix C). A more inclusive discussion of the relations of insects and air pollution appear in a paper delivered at the Fort Union Coal Field Symposium in Billings, Montana, April, 1975. This paper appears as Appendix D of this report.

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SECTION VIII

THE EFFECTS OF COAL-FIRED POWER PLANT EMISSIONS ON VERTEBRATE ANIMALS IN SOUTHEASTERN MONTANA

(A REPORT OF PROGRESS)

by

Robert A. Lewis, Martin L. Morton and Susan C. Jones

INTRODUCTION

To address the overall goals of the Montana Coal-Fired Power Plant Project (Lewis, Lefohn and Glass, 1975) we are attempting to identify: (a) those populations (or taxa) of birds and mammals in the study area that are most sensitive to air pollution; (b) those species, systems, and functions that may serve as specific, "noise-free" indicators of pollution (e.g., physiologic control systems); (c) population components that may serve as a measure of impact in the sense that they themselves are ecosystem resources or are coupled to ecosystem resources. We shall attempt to relate, if possible, functions of types (b) and (c) to evolve extrapolative or predictive models. We hope to determine the extent of pollution-related effects on small mammal and bird populations in the study area, and if possible, to distinguish between direct and indirect air pollution effects and effects of other human activities that might tend to confound our results (e.g., effects of coal-mining, water use, increased human population density, use of herbicides and pesticides, etc.).

Major objectives of the vertebrate animal investigation are to:

1. Measure and predict change in population structure and/or dynamics of selected species of birds and mammals as a function of air pollution, endogenous and exogenous cycles, and other environmental information including relevant biotic interactions and physical factors.

2. Evaluate physical and biotic factors that influence the dynamic-structural processes under investigation.

3. Identify, if possible, specific pollution effects on animal populations or systems.

4. Identify physiologic and population functions that contribute to the regulation of selected populations and evaluate the mechanisms whereby such regulation is effected, so that we may better interpret the causes of changes. We may thus increase our understanding of pollution-related effects and the confidence in our output.

5. Evaluate certain physiological, biochemical, and behavioral functions that may have potential for sensitive assay of pollution challenge. We hope to identify low levels of pollution stress before serious or irreversible effects occur.

Animal response to air pollution challenge varies seasonally, as a function of resource availability, as a function of sex and age, and in response to secondary stress from diverse sources (e.g., high population density, disease, competing or interacting populations, other pollutants).

Consequently, this work relies heavily upon baseline evaluation of annual cycle and life cycle phenomena and the mechanisms that regulate such functions. We hope that appropriate analysis of the temporospatial relationships of observed changes in animal function can be related to those of other ecosystem components that are under investigation (e.g., plant community structure) so that predictive relationships can be established.

Based on our interpretation of the literature of environmental physiology, toxicology, and to a lesser extent upon health related studies of air pollution effects, we anticipate that power plant emissions may affect almost all levels of animal organization. However, we do not know the "threshold" exposure rates that might be expected to produce various biological effects. This naiveté (coupled with the low pollution levels anticipated from the facility under investigation) has strongly conditioned our approach. Thus, the investigation is based more upon the application of what we believe to be sound biological principles than upon the application of the results of air pollution science or of health effects studies.

The very limited literature (to be reviewed in a later publication) that deals with the effects of low levels of pollutants from coal-fired power plants on animals is, nevertheless, encouraging and suggests that:

1. Some birds may be especially susceptible to gaseous emissions from coal-fired power plants.

2. Dispersion of animals about a stationary source, in response to air pollution, may change within a very short time.

3. At low levels of pollution, transient effects are likely to occur.

4. Birds are especially sensitive during the breeding season; the longer the breeding season, the greater the damage sustained.

5. Changes in organ weights occur in response to ambient pollution levels that are well below present standards. For example, in one study, increased weights of liver, kidneys, spleen and adrenal glands occurred (starting at 30 days) in white rats

exposed to polluted air containing SO_2, SO_3 mist, and airborne dusts at very low concentrations (i.e., 0.034-0.077 ppm, 6.7-9.5 $\mu g/m^3$ and 0.076-0.128 mg/m^3, respectively). Clean room controls did not exhibit these changes. The increase in liver weight was transient.

6. Protein metabolism is altered at very low pollution levels in some animals; a negative nitrogen balance may be induced. For example, in one study, flue gas (mixed with air) with an SO_2 concentration of 1 mg/m^3 produced a decrease in liver protein of guinea pigs.

7. Lung damage occurs in some birds at low pollutant levels. This is apparently due in part to the poor filtering ability of the nasal passage. Doves in polluted areas (Japan) sustain far greater lung damage than humans.

8. Chronic low levels of NO_x impair lipid metabolism of guinea pigs and may exert an arteriosclerotic effect.

9. Acetylcholinesterase (blood and liver), ascorbic acid (liver, lung, and perhaps other organs), spleen dehydrase, and carbohydrase concentrations may provide sensitive measures of air pollution in terrestrial vertebrates.

10. Species of vertebrates vary widely in their responses and sensitivities to air pollution. The standard laboratory animals maintained under good conditions of housing and nutrition are possibly much less sensitive to pollutant-induced stress than some of the more sensitive feral animals.

The scope of work is such that not all components can receive the same intensity of effort. Components are listed below in order of decreasing priority:

I. Reproductive and developmental biology.

II. Measures of condition, physiologic stress, homeostasis, and adaption.

III. Population biology.

IV. Histological cycles of organ-systems of potential or probable concern.

V. Niche selection and resource utilization.

VI. Experiments.

Briefly, the reproductive and developmental portion of the study focuses on the description of the annual reproductive cycles of a small set of indigenous species together with the growth and development of young to include information on bioenergetics, productivity, and the regulation of reproductive processes and of postnuptial molt (birds). The species of primary concern are the Mourning Dove (*Zenaidura macroura*), Western Meadowlark (*Sturnella neglecta*), Lark Bunting (*Calamospiza melanocorys*), Vesper Sparrow (*Pooecetes gramineus*), Lark Sparrow (*Chondestes grammacus*), Deer Mouse (*Peromyscus maniculatus*), and Prairie Vole (*Microtus ochrogaster*). The second or physiological component treats a number of types of functions, notably those that reflect condition and vigor of the animals and their stress responses. The third phase of the investigation treats population processes and some of the mechanisms that effect population adjustments (e.g., fecundity, mobility). The fourth phase, the evaluation of histological cycles, is designed to support the other components. Since it is impossible to fully anticipate which tissues or organ systems may be most affected by chronic pollution challenge, we are maintaining a tissue bank of the major organs that might be expected to show involvement.

Laboratory experiments will be conducted to test field-generated or model-generated hypotheses and/or to identify specific pollution effects suggested by observed field responses.

REPRODUCTION AND DEVELOPMENT

The reproduction component of this investigation overlaps and supports the population component. The reproductive and life cycles are of special and independent concern. We feel that significant impairment of animals at the population level will be reflected in altered reproductive performance and/or developmental patterns.

The reproductive cycle of North Temperate Zone vertebrates is, in general, the best characterized of the annual subcycles. Furthermore, regulatory mechanisms are fairly well known (Farner and Lewis, 1971; Lewis and Orcutt, 1971; and Sadlier, 1969). We are thus in an excellent position to assess the effects of air pollution on reproductive functions.

Lowered maturation rates to the time of nest departure of altricial birds and rodents, by whatever agency (e.g. air pollution), would increase the period of time that the young remain in the nest and their period of dependence upon parental care. They would thus be exposed to relatively high predation rates for a longer than normal period and also both the parents and the young might suffer a competitive disadvantage during and immediately following departure from the nest.

Immature mammals and birds may be especially sensitive to pollution. Furthermore, rates of growth and development can be easily related to several functions under study in other components of the Montana Coal-Fired Power Plant Project (see the introductory chapter of this report by Lewis, Lefohn, and Glass). Our study of development is restricted to a few indigenous bird and mammal species and treats the following:

1. Growth and maturation rates and phenology.

2. Biometry of growth.

3. Growth and development in relation to:

    a. Plant community structure and change.
    b. Climate
    c. Nutritional environment.
    d. Pollution concentrations.
    e. Molt progress and intensity.

4. Caloric and nitrogen balance as indicators of condition and ability to obtain and utilize nutritional resources.

5. Covariance of the above functions with physical environmental factors and air pollution gradients.

CONDITION, STRESS, ADAPTATION AND DISEASE

This phase of the vertebrate research deals with a number of functions and systems that may be expected to reflect the health and condition of the animals under investigation. Of particular interest are the following:

1. Bioenergetics (to include body weights, body composition [water, lipid, etc.], growth rates) and nutritional biology.

2. Adrenocortical system and responses to stress (e.g., general adaptation syndrome of mammals).

3. Immunobiologic responses (e.g., blood and reticuloendothelial system responses).

4. Disease and histopathology.

5. Behavior patterns (e.g., mobility, territorial behavior, niche utilization, etc.).

The measures of condition that we employ are regulated functions. That is, they tend to be maintained within relatively narrow limits at any given stage of the annual cycle. Such functions are, of course, frequently age- and sex-dependent. We expect some of these to provide relatively stable frames of reference against which environmental impacts can be measured.

To the extent that time and resources permit, food habits (mammals and birds) will be evaluated in order to establish whether observed effects are mediated by the nutritional environment. To this end, we are collecting seeds in the study area. Our seed collection to date consists of specimens of 17 species provided by John E. Taylor (Montana State University). This reference collection will be extended by us during the coming season.

POPULATION BIOLOGY

In this component we are attempting to assess changes in population size and structure of several indigenous species as a function of mortality, recruitment rates and life cycle functions. Ultimately, we would like to be able to predict changes in any or all of these as a function of pollution intensity. Also, we would like to determine the growth potential of the populations of concern. That is, we would like to establish the capacity of these populations to tolerate, or to recover from, challenge (especially from air pollutants) or perturbations that alter life functions and thereby tend to reduce the population or alter its composition.

Because of the relatively low signal-to-noise ratio in many population dynamic functions, we may expect the short-term chronic effects of air pollutants on population parameters to be small relative to natural and/or random variation. Appropriate sensitive analysis requires: (a) a pollution gradient across study sites (mammals and perhaps birds); (b) employment of reference sites that will allow us to estimate variations both between and within years (birds and mammals); (c) investigation and characterization of responses that may be pollution specific (birds and mammals); (d) investigation of associated functions that may represent deviations from the normal pattern or the phase-shifting or uncoupling of normally coupled phenomena; (e) evaluation of changes in population structure rooted in a study of annual cycle and life cycle components (e.g., time-based changes in sex and age structure, breeding success, etc.).

HISTOLOGICAL CYCLES OF ORGAN-SYSTEMS OF POTENTIAL OR PROBABLE CONCERN

A system of tissue banking has been initiated; several tissues and organs of the animals collected in the field are fixed and routinely embedded. As pollution-sensitive species and tissues are identified, appropriate specimens will be stained and examined histologically. Organ-systems of probable importance include the respiratory system, blood, adrenocortical system, reticuloendothelial system, liver, and the reproductive system.

NICHE SELECTION AND RESOURCE UTILIZATION

We have undertaken a quantification of major niche (habitat) dimensions on the mammal trapping grids. Prairie voles and deer mice occur together on all grids (i.e., are captured at the same trapping stations). Our analysis will include food habits (analysis of fecal pellets); shrub density; foliage profile diversity; extent of "aboreal" habitat and depth of the perennial grass mat.

Ground data will be augmented by high resolution (color or color-infrared aerial photography and the identification and mapping of the vegetation.

PROGRESS TO DATE

Collections of small mammals and birds using standard mark and release methods were initiated at five stations situated from 8-24 km from the plant.

Birds were trapped at fixed stations (1974) by the use of four 12 meter mist nets that are set at dawn and usually operated until noon. Birds captured were banded with U.S. Fish and Wildlife Service numbered bands, weighed, examined for sex, breeding condition (degree of development of the brood patch; cloacal protuberance) molt, ectoparasites, and then released at the site of capture. A total of 318 birds, representing 33 species, were banded and released. Of these, only 6 percent (two species) occurred at all of the netting stations and only 30 percent were present at more than one site (Table VIII-1). Because of personal limitations and the relatively high cost/benefit ratio, this component of the animal investigation has been discontinued.

Table VIII-1.
BIRD SPECIES BANDED AND RELEASED

Species	Number	% Total
1. Vesper Sparrow	80	25.3
2. Lark Sparrow	78	24.7
3. Western Meadowlark	22	7.0
4. American Robin	20	6.3
5. Red Crossbill	19	6.0
6. Yellow Warbler	17	5.4
7. Savannah Sparrow	14	4.5
8. Catbird	10	3.2
9. American Redstart	7	2.2
10. American Goldfinch	6	1.9
11. Red-winged blackbird	5	1.6
12. Mourning Dove	4	1.3
13. Eastern Kingbird	4	1.3
14. Lark Bunting	4	1.3
15. Red-shafted flicker	3	1.0
16. House Wren	3	1.0
17. Downy Woodpecker	2	0.6
18. Starling	2	0.6
19. Black-headed Grosbeak	2	0.6
20. Yellow-brested chat	2	0.6
21. Brewer's blackbird	2	0.6
22. Brown-headed Cowbird	1	0.3
23. Roufous-sided Towhee	1	0.3
24. Red-eyed Vireo	1	0.3
25. Brown Thrasher	1	0.3
26. Audubons Warbler	1	0.3
27. Loggerhead Shrike	1	0.3
28. Red-headed Woodpecker	1	0.3
29. Black-capped Chickadee	1	0.3
30. Bullocks Oriole	1	0.3
31. Western Flycatcher	1	0.3
32. Winter Wren	1	0.3
33. Ovenbird (1 unbanded)	1	0.3

TOTAL: 318 individuals, 33 species

A standard roadside census of birds, conducted from April through September at semimonthly intervals, continues. This census is patterned after the widely employed North American Breeding Bird Survey (Robbins and Van Velzen, 1970). The census route is depicted in Figure VIII-1. We expect this census to provide fairly sensitive data on changes in species diversity; changes in relative and absolute abundance; changes in dispersion in relation to the coal-fired power plant at Colstrip; and supplemental information on sex and age ratios, productivity and the annual calendar of some species. Based upon the combined results of netting and censusing, the most abundant and widely-distributed grassland bird species that breed in the study area are the Western Meadowlark, Vesper Sparrow and Lark Sparrow (Tables VIII-1 and VIII-2).

In addition, bird specimens are collected via shotgun at various locations both within the study area (but never closer than one mile from the sites where live animals are studied) and in reference areas in Rosebud and Powder River counties.

Bird specimens collected by shooting are used for carcass analysis and histological study. Five species are specifically sought: the Vesper Sparrow, Lark Sparrow, Western Meadowlark, Mourning Dove, and Lark Bunting. Immediately following collection, organs or tissues that are to be assessed histologically are removed (in the field) and placed in the appropriate fixative. The carcass is then placed in a sealed plastic bag and retained in an ice chest for no more than a few hours. Upon return to the field laboratory, the carcass is immediately weighed on a O'haus dial 0-gram balance with an accuracy of ± 0.05 g and placed in five nested plastic bags and retained in a freezer at -5°C until shipment via air freight in dry ice to the Corvallis laboratory where the specimens are processed as soon as possible. The bird collections are generally made twice weekly.

Figure VIII-1. Map of the Rosebud-Colstrip roadside census route (birds).

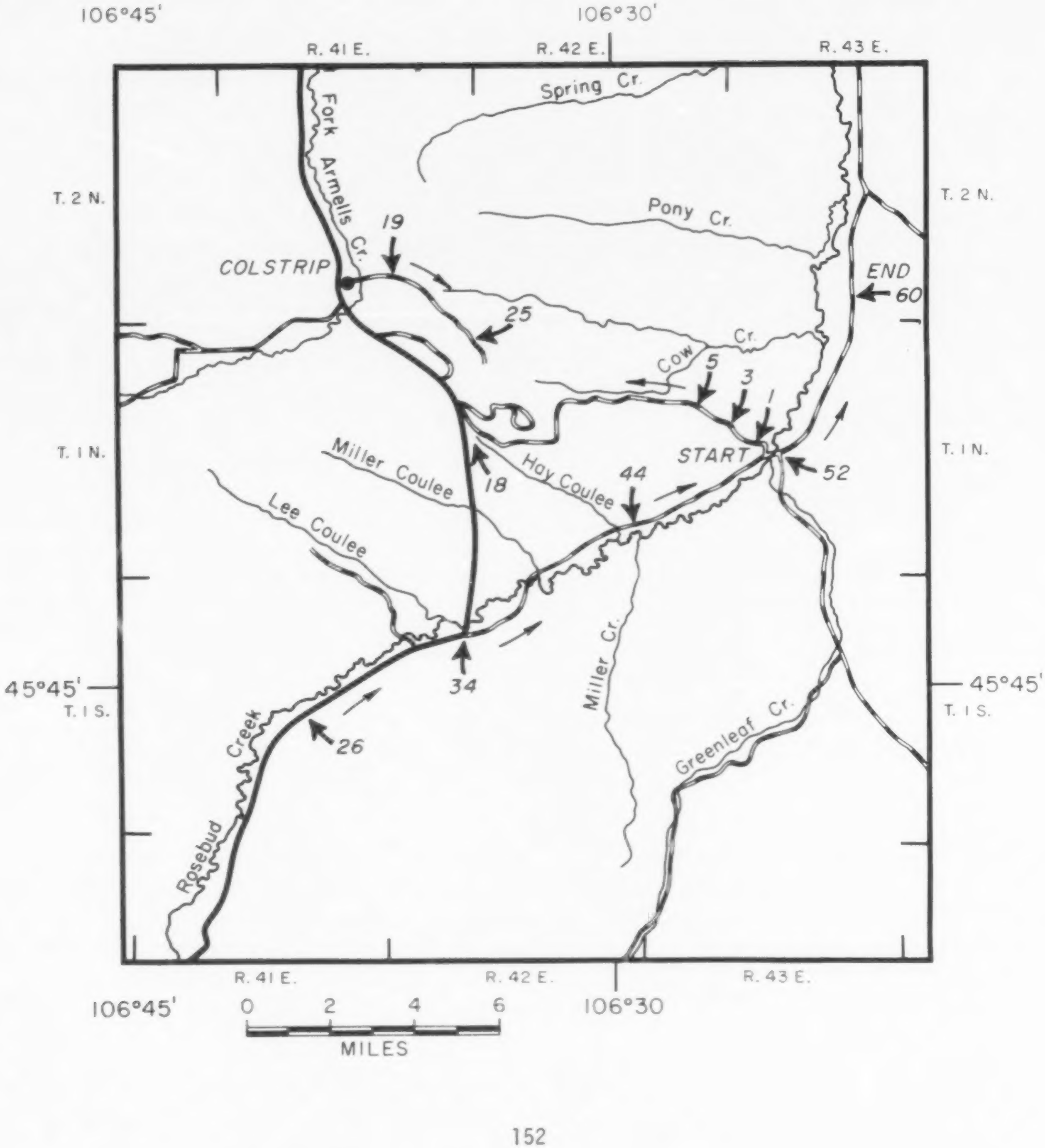

106°45'
106°30'
R. 41 E.
R. 42 E.
R. 43 E.
T. 2 N.
T. 1 N.
T. 1 S.
45°45'
Spring Cr.
Fork Armells Cr.
Pony Cr.
COLSTRIP
19
25
END
60
Cow Cr.
5
3
1
START
52
Miller Coulee
18
Hay Coulee
44
Lee Coulee
Miller Cr.
34
26
Rosebud Creek
Greenleaf Cr.
0
2
4
6
MILES

Table VIII-2 Road-Side Census Rosebud-Colstrip
6 May, 1975, 0532-1215 hr

-SPECIES-	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
							-STATIONS-								
Sparrow Hawk				2		1								1	
Red-tailed Hawk															
Marsh Hawk			1	1											
Rough-legged Hawk															
Ring-necked Pheasant	4							1							
Sharp-tailed Grouse			1												
Mourning Dove	2	1						1	4	3			1		
Poor-will															
Common Nighthawk															
Red-shafted Flicker				1							2				
Red-headed Woodpecker															
Western Kingbird															
Eastern Kingbird															
Cassin's Kingbird															
Say's Phoebe															
Barn Swallow															
Black-billed Magpie			2												
Common Crow															
Black-capped Chickadee								3		3	13?				
Robin												2			
Audubon's Warbler															
Yellow Warbler															
Brewer's Blackbird									3		1				
Red-winged Blackbird															
Common Grackle															
Western Meadowlark	4	7	5	5	10	10	6	5	5	3	5	6	5	8	6
American Goldfinch															
Rufous-sided Towhee															
Vesper Sparrow															
Lark Sparrow															
Savannah Sparrow															
Other Species															
Starling							8								
Owl?	1														
Woodpecker?			1	1											
Buteo							2								
Common Snipe	1														
Killdeer													1		

Table VIII-2 (continued)

-SPECIES-	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Sparrow Hawk		2					4	1			1	1	1		
Red-tailed Hawk														1	
Marsh Hawk														1	
Rough-legged Hawk															
Ring-necked Pheasant											1	2	2	2	
Sharp-tailed Grouse													2		
Mourning Dove															
Poor-will															
Common Nighthawk															
Red-shafted Flicker															
Red-headed Woodpecker															
Western Kingbird															
Eastern Kingbird															
Cassin's Kingbird															
Say's Phoebe					1	1									2
Barn Swallow															
Black-billed Magpie															
Common Crow												2	3		
Black-capped Chickadee															
Robin															
Audubon's Warbler															
Yellow Warbler															
Brewer's Blackbird							8							10	
Red-winged Blackbird				14			2	3							4
Common Grackle															
Western Meadowlark	3	2	4	--	3	1	2	4	2	3	9	4	3	10	4
American Goldfinch															
Rufous-sided Towhee															
Vesper Sparrow	3		2		6						3			3	
Lark Sparrow															
Savannah Sparrow											1				
Other Species															
Yellow-throat				1											
Siskin-sized bird						20									
Loggerhead Shrike											1				
Woodpecker														1	
Buteo															

Table VIII-2 (Continued)

-SPECIES-	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Sparrow Hawk			2	1		2							1		
Red-tailed Hawk															
Marsh Hawk															
Rough-legged Hawk															
Ring-necked Pheasant		2	1	1	2				3				1	1	1
Sharp-tailed Grouse								3							
Mourning Dove		10													
Poor-will															
Common Nighthawk															
Red-shafted Flicker															
Red-headed Woodpecker															
Western Kingbird															
Eastern Kingbird															
Cassin's Kingbird															
Say's Phoebe			1												
Barn Swallow															
Black-billed Magpie															
Common Crow							1		2						
Black-capped Chickadee															
Robin		2						2	2						
Audubon's Warbler															
Yellow Warbler															
Brewer's Blackbird	5	20	1	2			4	4		1					
Red-winged Blackbird														2	
Common Grackle															
Western Meadowlark			9	5	1	4	6	7		6	5	1	6		5
American Goldfinch															
Rufous-sided Towhee									1						
Vesper Sparrow											3	3		3	
Lark Sparrow															
Savannah Sparrow															
Other Species															
Loggerhead Shrike				1			1								
Unidentified Sparrow															75
Long-eared Owl															1

-STATIONS-

Table VIII-2 (Continued)

-SPECIES- -STATIONS-

	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Sparrow Hawk	1						1		1	2		1		2	
Red-tailed Hawk															
Marsh Hawk									1						
Rough-legged Hawk															
Ring-necked Pheasant		1			1	2	4	2	4	2	2	3	3		2
Sharp-tailed Grouse															
Mourning Dove		1							2						
Poor-will															
Common Nighthawk															
Red-shafted Flicker							1								
Red-headed Woodpecker															
Western Kingbird															
Eastern Kingbird															
Cassin's Kingbird															
Say's Phoebe															
Barn Swallow															
Black-billed Magpie															
Common Crow															
Black-capped Chickadee															
Robin															
Audubon's Warbler															
Yellow Warbler															
Brewer's Blackbird										3	2				
Red-winged Blackbird															
Common Grackle															
Western Meadowlark	7	5	8	6	9	10	2		3	4	4	6	3	3	6
American Goldfinch															
Rufous-sided Towhee									1						
Vesper Sparrow			5		3										
Lark Sparrow															
Savannah Sparrow				17	3										
Other Species															
Mallard							3								
Golden Eagle													1		
White-crowned Sparrow															2

Mammals are collected with two trapping systems, one for the collection of specimens for necropsy and another for mark-release data. Live traps are used in both systems.

1. Collections. Rodents are livetrapped one day per week and returned to the field laboratory for processing. Body weight and length measurements (body, ear, hindfoot and tail) are taken. Following ether anesthesia, blood is taken from the orbital sinus in a capillary tube. From this is determined hematocrit (via centrifugation) and plasma protein concentration (via diffraction meter). Heart, lungs, kidneys, adrenals, spleen, liver, gonads and oviducts are preserved in Bouins fixative, weighed after one week, and transferred to 70 percent ethanol for subsequent embedding. The frozen carcasses are saved for analysis of components. More than 200 small mammal specimens have been collected thus far. Femurs from 80 animals have been frozen and mailed to C. C. Gordon (University of Montana) for determination of fluoride content.

2. Mark-release. Grids with outside dimensions of 150 m x 150 m have been established at five locations. Trapping stations within each grid are 15 m apart; there are 121 stations/grid. Two traps are set at each station; a total of 242 traps/grid. The grids are trapped in regular rotation following three or four nights of prebaiting with rolled oats.

All rodents trapped are toe-clipped according to a standard numerical scheme, weighed, measured, and examined for external signs of sexual activity and other factors such as ectoparasites and pelage changes. Releases are made at the station of capture. By midwinter 313 individuals had been marked and released.

A total of 305 recaptures have occurred. The species captured, in ascending order of frequency, are the Grasshopper Mouse (*Onchomys leucogaster*), Harvest Mouse (*Reithrodontomys megalotis*), Olive-backed Pocket Mouse (*Perognathus fasciatus*), Prairie Vole (*Microtus ochrogaster*), and Deer Mouse (*Peromyscus maniculatus*) (Table VIII-3).

The percentage of each species comprising our catch on the five grids varies seasonally (Figure VIII-2). Numerous interacting factors account for this variation and these undoubtedly vary among species. In the case of *Onychomys leucogaster*, for example, none were captured until the grasshopper population experienced a sharp decline in August. Beyond October neither *O. leucogaster* nor *Perognathus fasciatus* were captured and both species are presumed to have entered hibernation. Nearly all specimens of *P. fasciatus* were captured on two nights when traps were left open during rainstorms.

Peromyscus maniculatus comprised from 52 to 79 percent of the total catch during every month. *Microtus ochrogaster* also made up a fairly consistent portion of the catch, 13 to 33 percent, although they were not taken at every trapping session as was the case for *P. maniculatus*.

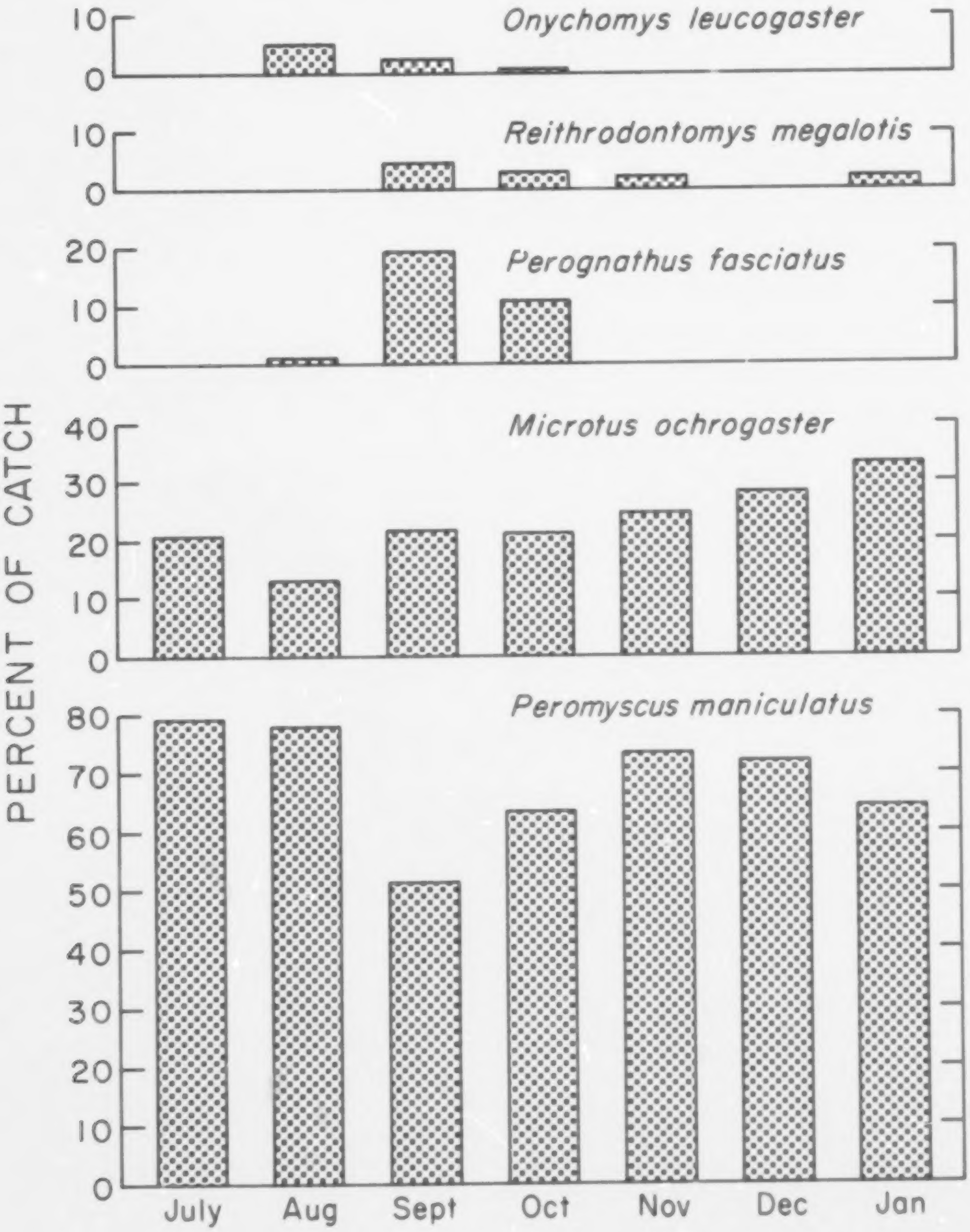
Traps that are set within a network of *M. ochrogaster* runways will often take more *P. maniculatus* than *M. ochrogaster*. And at grid stations where animals have been captured, *P. maniculatus* only have been taken at 80 percent of the stations, *M. ochrogaster* only at eight percent of the stations, and both have been taken at 12 percent of the stations. On three occasions members of each species have been taken during the same night at the same station. Thus *P. maniculatus* and *M. ochrogaster* are locally sympatric in the Colstrip area. This is unexpected since distributional and behavioral studies indicate that these groups are usually allopatric or only geographically sympatric and that differential habitat utilization occurs because of interspecific competition (Pearson,

Table VIII-3. NUMBERS OF MICE CAPTURED ON GRIDS AND TRAPLINES IN COLSTRIP AREA. JULY 1974-April 1975

	GRID				
Species	No. Captures	No. Recaptures	Trapline Captures	Total Captures	%
Onychomys leucogaster	7	6	1	14	1.3
Reithrodontomys megalotis	12	1	12	25	2.4
Perognathus fasciatus	21	8	6	35	3.3
Microtus ochrogaster	75	56	44	175	16.5
Peromyscus maniculatus	260	290	262	812	76.5
Totals	*375	361	325	1061	

*indicates number of individuals that were marked and released.

Figure VIII-2. Seasonal changes in species composition of rodents captured on grids near Colstrip, Montana, in terms of trapping frequency. Note that Onychomys and Perognathus are hibernators.



1959; Wirtz and Pearson, 1960; Shure, 1970; Murie, 1971). We are aware of only one previous case of local sympatry in these groups, that in a wet prairie environment in Southern Ontario (M'Closkey and Fieldwick, 1975).

This is not to say that interspecific competition is absent when these species occur together. Members of these groups are not distributed randomly in Colstrip populations and they undoubtedly occupy separate niches, however subtly structured.

We expect our analysis of niche dimensions involved in the ecological separation of Peromyscus and Microtus in relatively arid shortgrass prairie to be important for comparative purposes and for testing the applicability of models such as those that deal with utilization of space by small mammals (Calhoun, 1963; Myton, 1974).

Our routine trapping of grids is yielding demographic information, particularly on P. maniculatus. The proportion of adults in our samples decreased in autumn (Figure VIII-3). Reproduction ceased in December and the proportion of adults increased through the winter as young animals continued to attain adult size and pelage. Males formed a remarkably constant proportion of the catch, about 60 percent in all months (Figure VIII-3). The sex ratio observed in 621 captures of P. maniculatus was 1.52:1. This is an unbalanced sex ratio that deviates significantly from 1:1 ($P < 0.005$) according to a chi-square test.

Body weights of P. maniculatus showed considerable seasonal variation (Figure VIII-4). This variability is expected in immatures because of growth and constant recruitment and in adult females because of varying reproductive status. Adult males show much less variation; however, a slight but regular increase in mean body weight occurred from July through January. Our analysis of whole body composition should reveal the basis for this increase (e.g., pelage growth or fattening).

Figure VIII-3. Sex and age distribution of Peromyscus maniculatus captured near Colstrip, Montana, 1974-75. Numbers in parentheses indicate total catch.

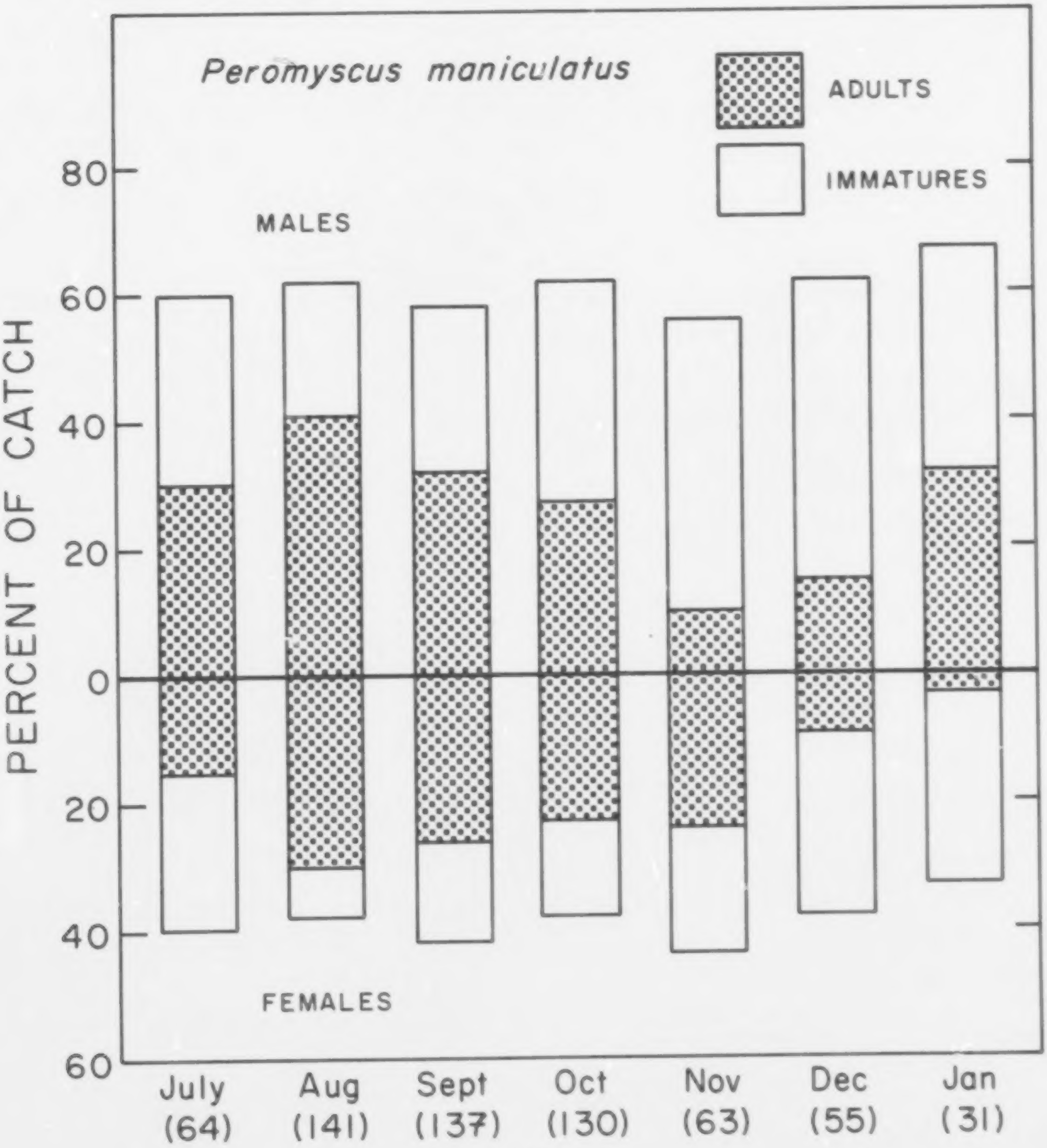


Figure VIII-4. Seasonal change in body weight of Peromyscus maniculatus trapped in the Colstrip, Montana, area.

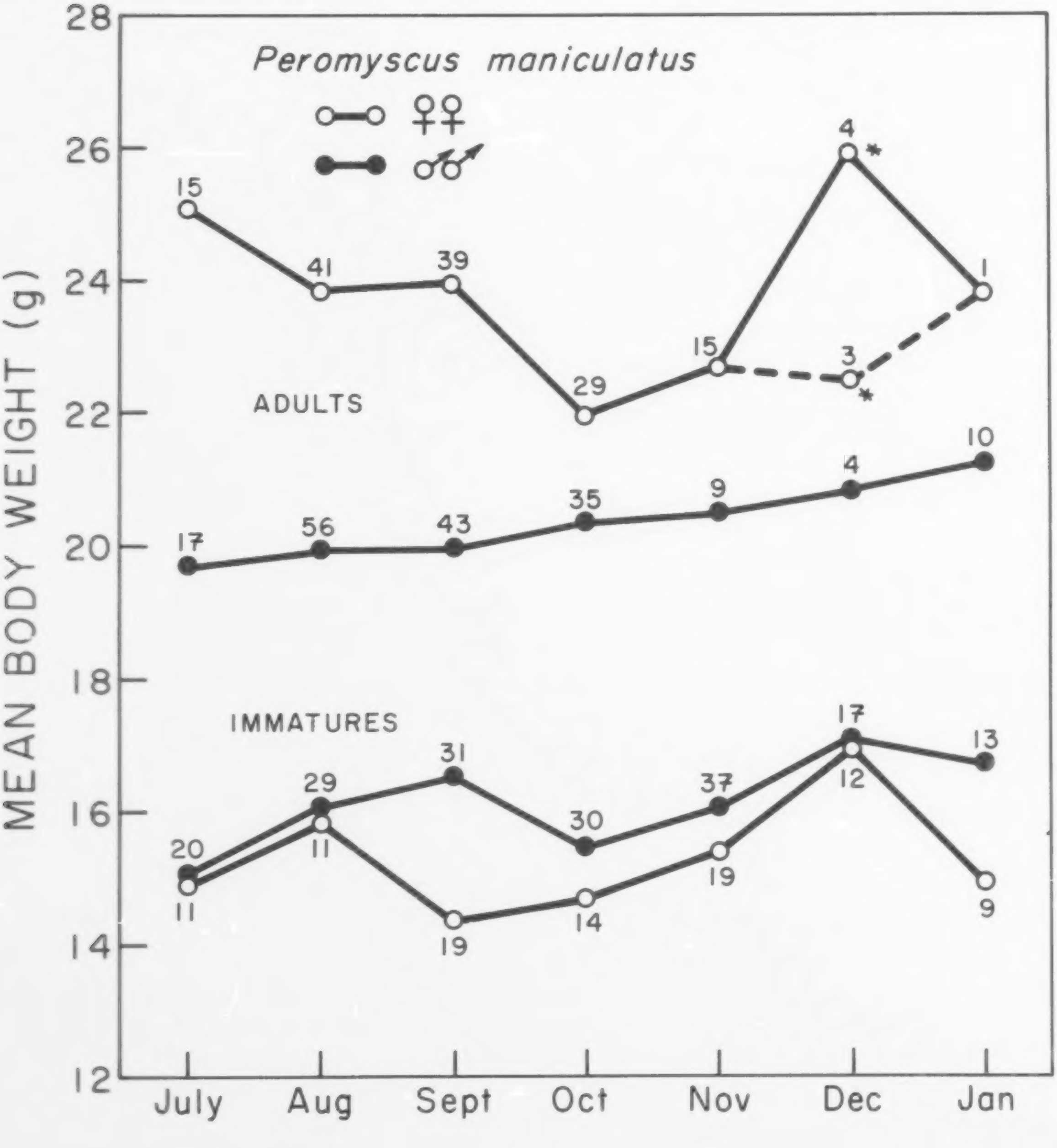
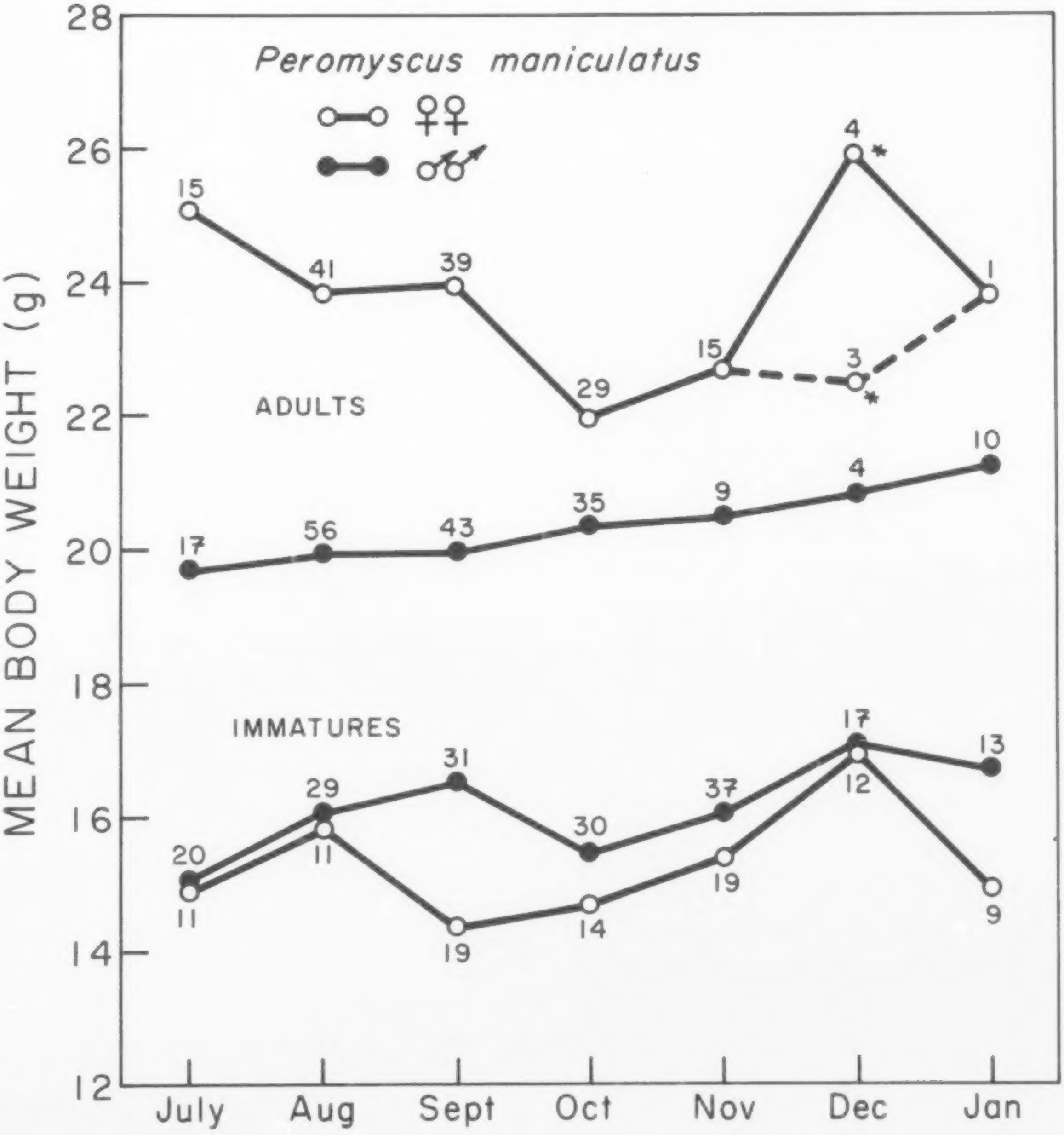


Figure VIII-4. Seasonal change in body weight of Peromyscus maniculatus trapped in the Colstrip, Montana, area.



Laboratory activities center about five sets of protocols.

1. Carcass analysis - birds
2. Carcass analysis - mammals
3. Histology - birds
4. Histology - mammals
5. Experiments

This work deals principally with four species of indigenous birds and two species of mammals.

Mourning Dove, *Zenaidura macroura*
Western Meadowlark, *Sturnella neglecta*
Vesper Sparrow, *Pooecetes gramineus*
Lark Sparrow, *Chondestes grammacus*
Prairie Vole, *Microtus ochrogaster*
Deer Mouse, *Peromyscus maniculatus*

Standard biometric methods and whole carcass and organ analyses of the rodents and birds are employed to evaluate composition and biometric changes as a function of age, sex, season, and physiologic state in relation to the physical and biotic environment. The main purpose of this type of analysis is to better assess condition, vigor, nutritional state, metabolic state, and net energy balance as a function of air quality and other environmental factors.

Major body and organ components to be measured and evaluated include wet body weight, dry body weight, fat-free dry weight, lipids, allometry of feather growth (birds) and of related functions, stomach and crop (birds) contents and weights, caloric density of the diet, parasite burdens (e.g., of intestinal tract and perhaps of blood).

Dietary and tissue (liver, muscle, contents of lower intestinal tract) protein levels are assayed by gas chromatography.

A copy of the "Dissection Worksheet for Whole Carcass Analysis," for birds is included as Appendix E, and a description of the procedures for carcass analysis of birds follows. The protocol for mammals (not included in this report) is similar to that of birds, except that most functions must be referred to dry weight and the organs of interest differ somewhat.

Carcass Analysis Procedure (Birds): Mammal and bird carcasses are shipped frozen to the Corvallis laboratory and stored in five nested plastic bags in freezers kept at -5°C. A designated number of carcasses are selected one day prior to dissection, the specimen numbers are noted and they are returned to the freezer until the morning of the dissection. Dissection containers are prepared in advance for each specimen. The containers are marked with specimen number and tissue; labels with the same information are inserted into the corresponding vials, the proper amount of 10 percent neutral formalin or saline (to maintain state of hydration) is added to the vials and the fat sample container is preweighed. All containers for each bird are kept together and stored in a dry dust free place.

On the morning of dissection, all the designated specimens are moved to the refrigerator; each bird is allowed to partially thaw just prior to its dissection. Three people are essential to the procedure, with an optional fourth person offering general assistance and taking wet weights of tissues periodically throughout the day. The dissection procedure closely follows the outline of the dissection worksheet (Appendix E). Standard methods are employed and will be described, as appropriate, in later reports. Organs and tissue samples of 10 mg or less are weighed on a Cahn Model 4100 electrobalance. Larger samples are weighed on a

Sartorius analytical balance, model 2462 (200 gr. cap., 0.1 mg sens.). Tissues are then either returned to the carcass (including the Bursa of Fabricius, adrenals, kidney, empty crop, empty gizzard, ovary, oviduct, testes and spleen) or are processed in some other manner. Prior to return to the carcass, the ovary is examined for measurement of pre- and postovulatory follicles and the oviduct is examined for the presence of ova. To obtain the dry weight of the carcass or other tissues, the samples, already in petri dishes, are placed, uncovered, in a Fisher Isotemp Vacuum oven, Model 201 at 40°C, 20" Hg. until a constant weight is reached. Time required will vary with sample size. Dry weights are recorded and the tissues are ready for further treatment. The remaining tissues that complete the analysis as part of the carcass are now returned to it, including the ventral apterium, integument, heart and lungs.

The carcass and all remaining samples (including pectoralis, fat, crop contents, and liver) are now individually ground in a Model 4-E Quaker City Laboratory Mill so the material will pass through a 35 mesh sieve. At this point, one or more random samples are taken from each tissue sample and formed into pellets, using the Parr 1/2" Pellet Press, Model 2811. These pellets are weighed and burned in a Parr model 12141 adiabatic bomb calorimeter to determine the dry weight calorie content.

The remainder of the fat sample is put in a tissue bank for possible future pesticide scan or trace elements analysis. The remainder of the crop contents sample as well as the dried intestinal contents are analyzed for carbon and nitrogen contents by a gas chromatographic method.

The remaining carcass, pectoralis and liver samples are now prepared for lipid extraction. Milled samples are wrapped in filter paper packets or cellulose extraction thimbles and processed in a soxhlet apparatus using 1,2-dichlorethane (Lewis, unpublished). The samples are dried at

65°C in a Thelco convection oven and the fat-free dry weights are recorded. Tissue samples are also taken for nitrogen analysis to be determined by gas chromatograph method. Following fat extraction, three homogenized random samples of the whole dry fat-free carcass or of a specific organ are burned in a Parr model 12141 adiabatic oxygen bomb calorimeter. A weighed fat-free dry sample of the carcass is also analyzed for ash content. This is determined by combustion in a muffle furnace at 600°C until a residue of constant weight is obtained.

Examples of preliminary results on growth, condition, and nutrition follow. These data illustrate the pronounced seasonal and diurnal changes that occur in many functions. These types of variation are pervasive in living systems and of concern in the study of pollution effects for at least two major reasons: (a) both experimental design and field sampling protocols must be structured to control or describe these kinds of variations, and (b) the sensitivities and exposure rates of animals to air pollutants and to other sources of stress vary both as a function of the time of day (Aschoff, 1965; Halberg, Jacobsen, Wardsworth, Bittner, 1958; Halberg, Johnson, Brown, and Bittner, 1960; Haus and Halberg, 1959) and time of year (Fretwell, 1972; Tashiro, Namie, Takemota, and Misazumi, 1974).

Figures VIII-5 and VIII-6 illustrate the enormous changes in the size and internal organization of reproductive tissues that may occur in periodically breeding vertebrates. In 1974, for example, testicular size decreased in P. maniculatus near Colstrip during September and October (Figure VIII-5). The testes remained at near minimum size during winter and did not become substantially enlarged until March (no males were collected in February). Parallel changes in functional capacity in these structures are demonstrated also by the annual cycle in seminal vesicle size, a measure of androgen release (Figure VIII-6). The first pregnant female of the new season was collected on March 25.

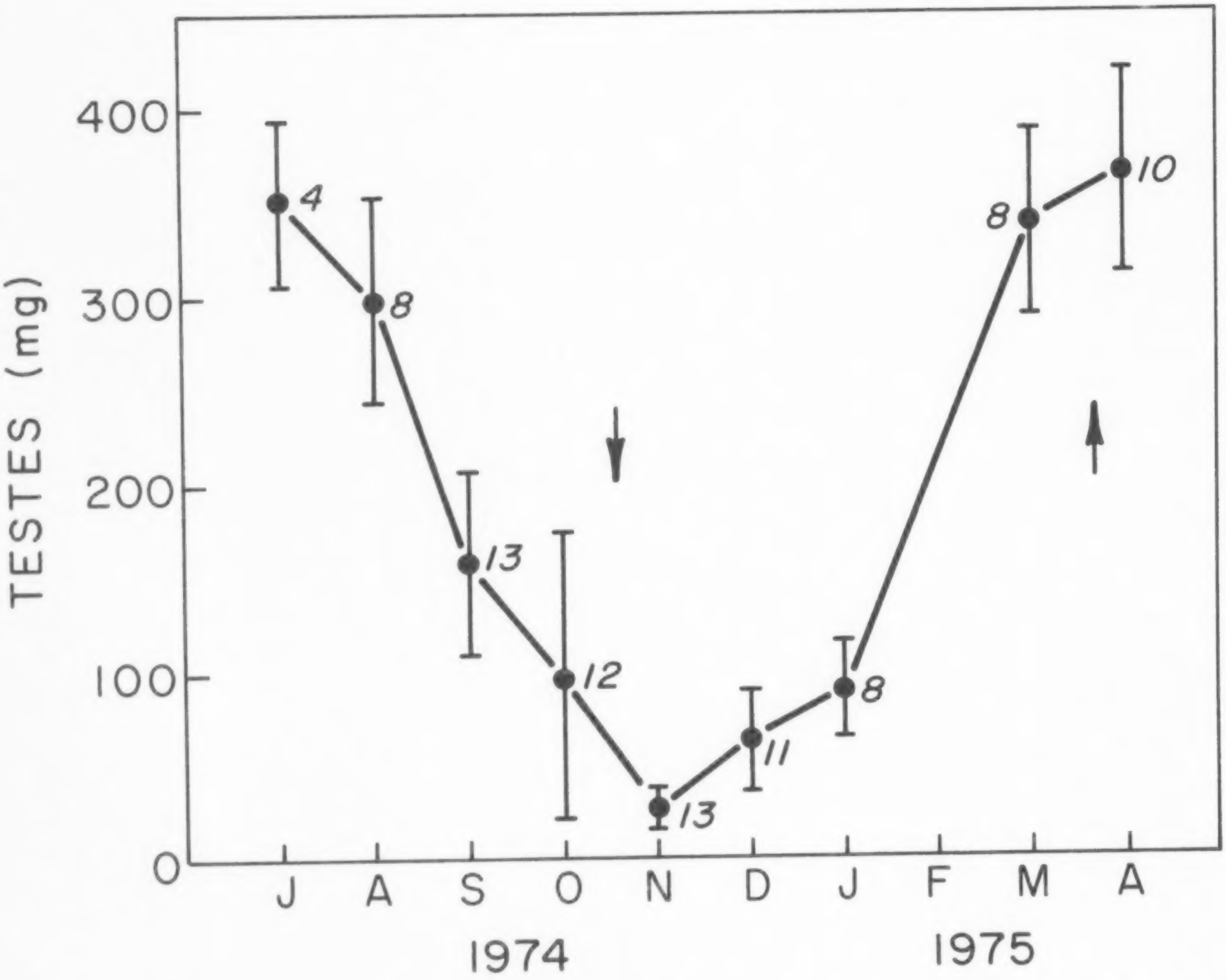
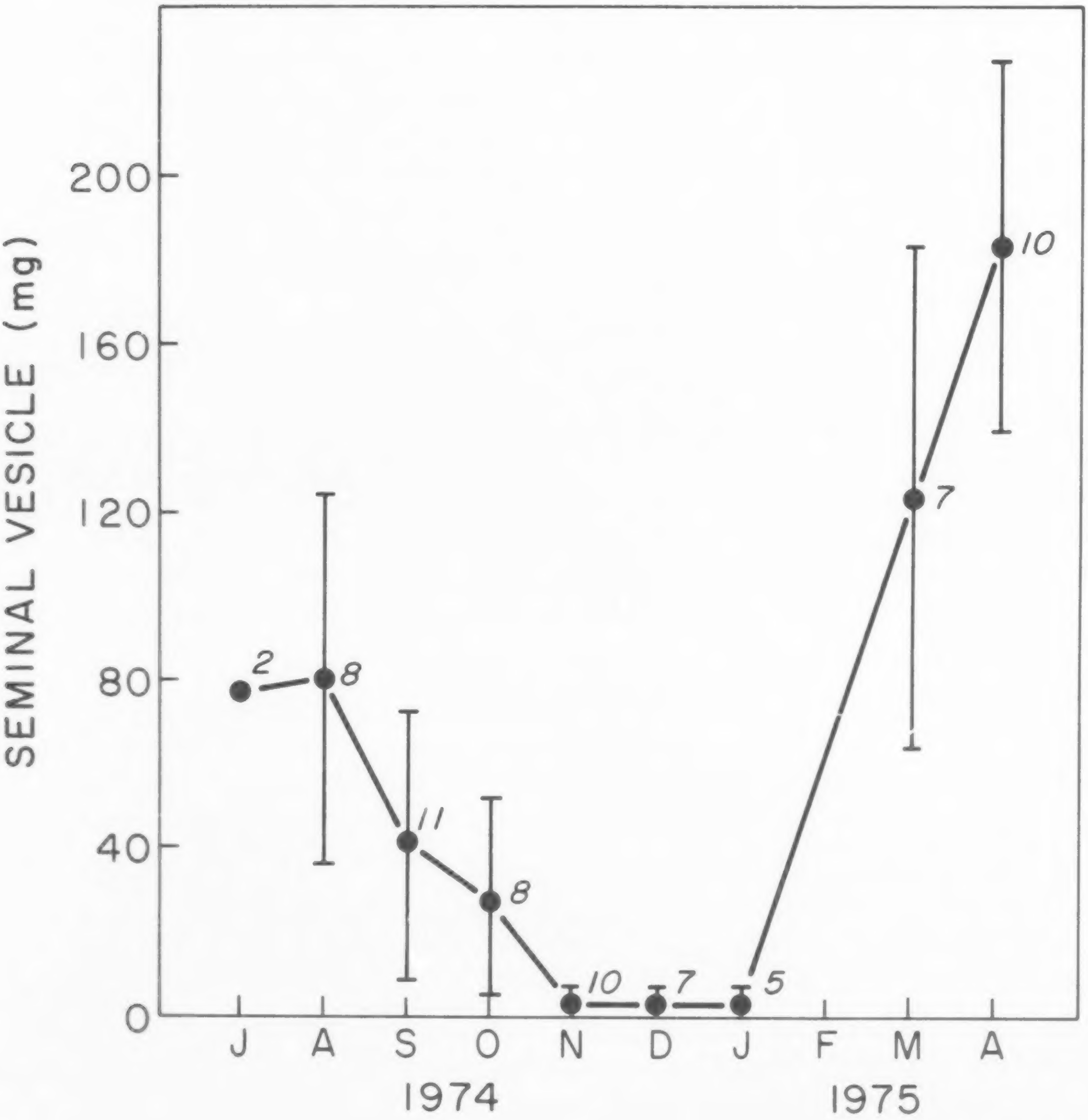


Figure VIII-5 Seasonal change in testicular weight of adult *Peromyscus maniculatus* captured near Colstrip, Montana. Means ± S.E. are shown. Down arrow indicates last pregnant female captured in 1974 and up arrow indicates first pregnant female captured in 1975. Numerals in parantheses indicate sample size.

Figure VIII-6. Seasonal change in seminal vesicle weight of adult Peromyscus maniculatus captured near Colstrip, Montana. Means ± S.E. are shown. Numerals in parentheses indicate sample size.



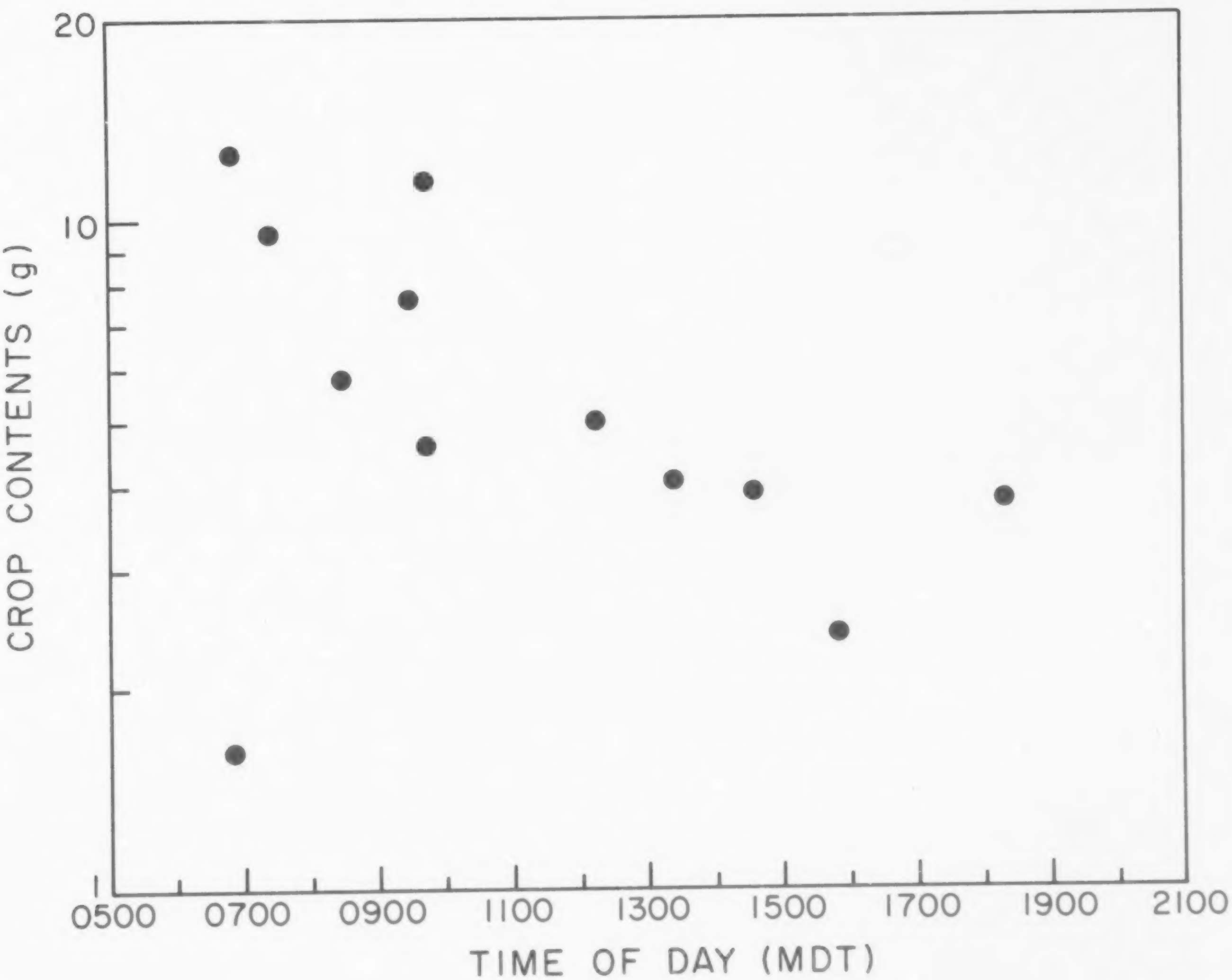
The reproductive cycle of *M. ochrogaster* is similar to that of *P. maniculatus* (Morton and Lewis, unpublished data). Experiments are planned whereby the environmental factors that regulate the annual sexual cycle of certain of the birds and/or mammals will be quantitatively assessed. Such studies are needed if we are to sensitively determine the effects of air pollutants on reproductive performance.

During the hot, sunny days of summer, Mourning Doves, *Zenaidura macroura*, feed intensively during the first few daylight hours and again late in the day. This activity cycle is reflected in the amount of food in the crop, a storage organ (Figure VIII-7). Clearly, the activity patterns and feeding rates of these wide ranging birds may influence both the rate of exposure and susceptibility to air pollutants. Consequently pollution effects may be a function of both the magnitude of the peak pollutant concentrations and the time of their occurrence. Interestingly, daily maxima in air pollution concentration from coal-burning processes frequently show strong diurnal cycles; see the chapter of this report written by Lee, Lewis and Body.

The body weight of adult male Mourning Doves does not appear to increase substantially during the early stages of postnuptial molt (Figure VIII-8). However, body weight rapidly increases following replacement of the fourth primary remex. Interestingly, in a number of specimens, we have found the molt to be arrested for an as yet undetermined length of time (probably about one week). Data thus far reveal no clear seasonal trend in body weight (Lewis and Morton, unpublished data); the lowest body weights on any given date occur in birds (male and female) with arrested molt. Furthermore, birds at molt stages six through eleven almost invariably weigh more than birds at stages zero through five.

These early data suggest that the earlier stages of molt in the Mourning Dove may be bioenergetically more costly than later stages. The brief cessation of molt may favor restoration of a favorable nutritional balance. The data further suggest that this species could be especially susceptible to environmental stressors during the period of molt.

Figure VIII-7. Daily variation in the weight of the crop contents of adult male Mourning Doves, *Zenaidura macroura*, September 9-10, 1974, near Colstrip, Montana.



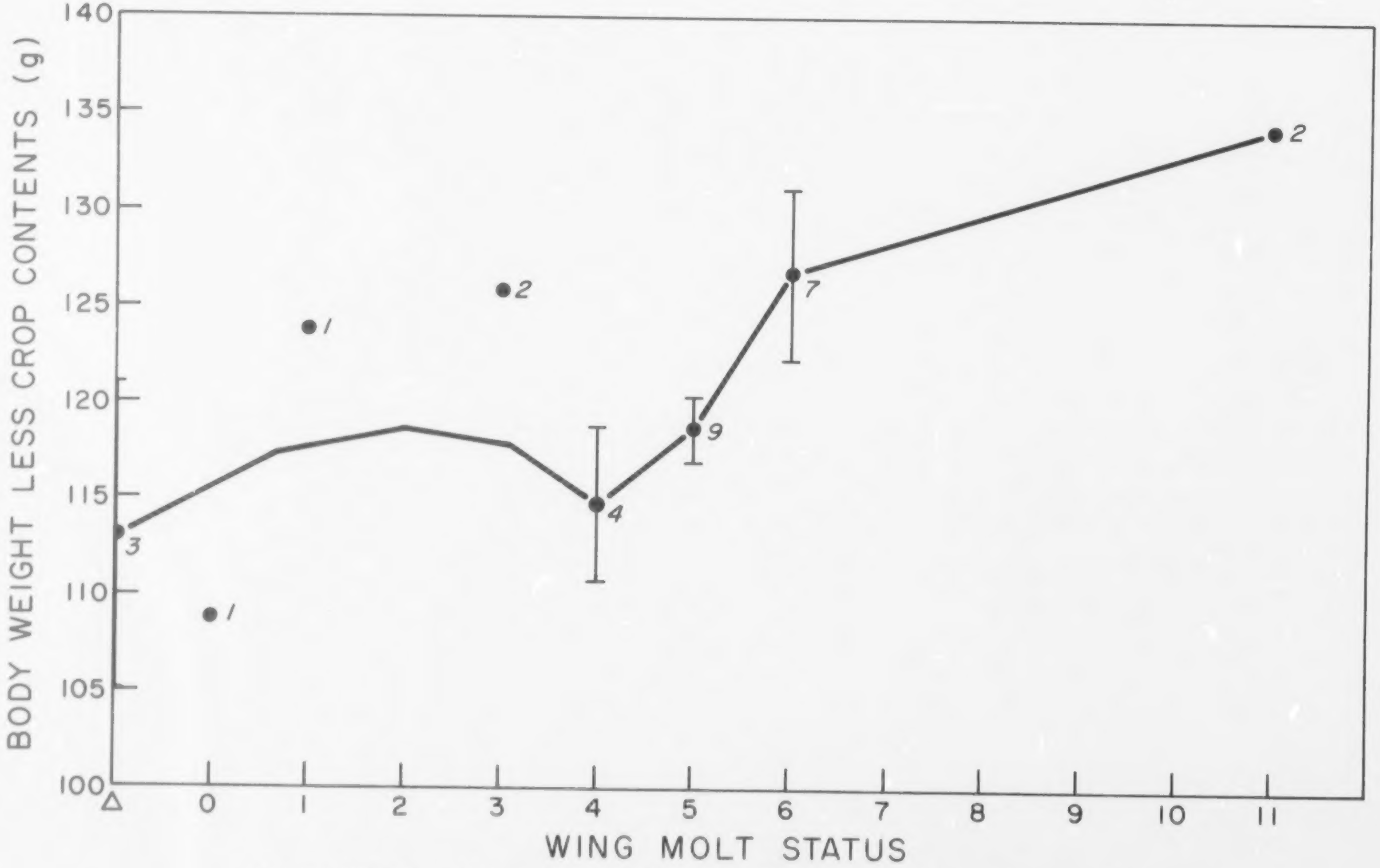


Figure VIII-8. Body weights of adult male Mourning Dove, Zenaidura macroura as a function of molt stage. Stage Δ represents interrupted molt; stage 0 is prior to onset of postnuptial molt; stages 1 through 10 represents the highest primary feather that is growing; and stage 11 treats birds in which molt is complete. Molt proceeds sequentially from 1 through 10.

The seasonal pattern of growth and development of male and female Western Meadowlarks, Sturnella neglecta (Figure VIII-9, VIII-10) that we observed in Rosebud and Powder River countries in 1974, differed substantially. The 1974 specimens are not yet fully processed, and sex has not been established for all birds. Nevertheless, data thus far evaluated suggest that the juvenile females may have a more limited capacity (in 1974) to convert nutritional resources into new tissue. Juvenile females may thus offer a useful system for evaluating the additional stress of air pollution. Body weight both as a function of season (Figure VIII-9) and developmental (i.e., molt) status (Figure VIII-10) differs in males and females. The differences in body weight appear to reflect differences in nutritional or energetic balance (Lewis and Morton, unpublished).

The molt schedule (Figure VIII-11) and the rate of growth of new plumage (Figure VIII-12) are similar in both sexes of juvenile Western Meadowlarks. However, while the body mass of the males as a group increases throughout the period of feather growth, most females appear to replace plumage at the expense of other body compartments (Figures VIII-13, VIII-14, VIII-15, Lewis and Morton, unpublished data). Supporting data on tissue calories and nitrogen will be available in a few weeks.

The postnuptial molt of Meadowlarks is a major molt during which all plumage is replaced. This molt results in a very considerable increase in the weight of the integument (Figure VIII-12) and, presumably, a corresponding decrease in thermal conductance. The bioenergetic demands and the environmental control mechanisms of postjuvenal and postnuptial molts have not been fully explored. Nevertheless, photoperiod, food, and microclimate all play a role in regulating molt (Payne, 1972).

The gizzard, or muscular stomach, of birds is an organ that acts, in part, as an organ of mechanical digestion. Because muscles typically hypertrophy with increased loading, we would expect the mass of the

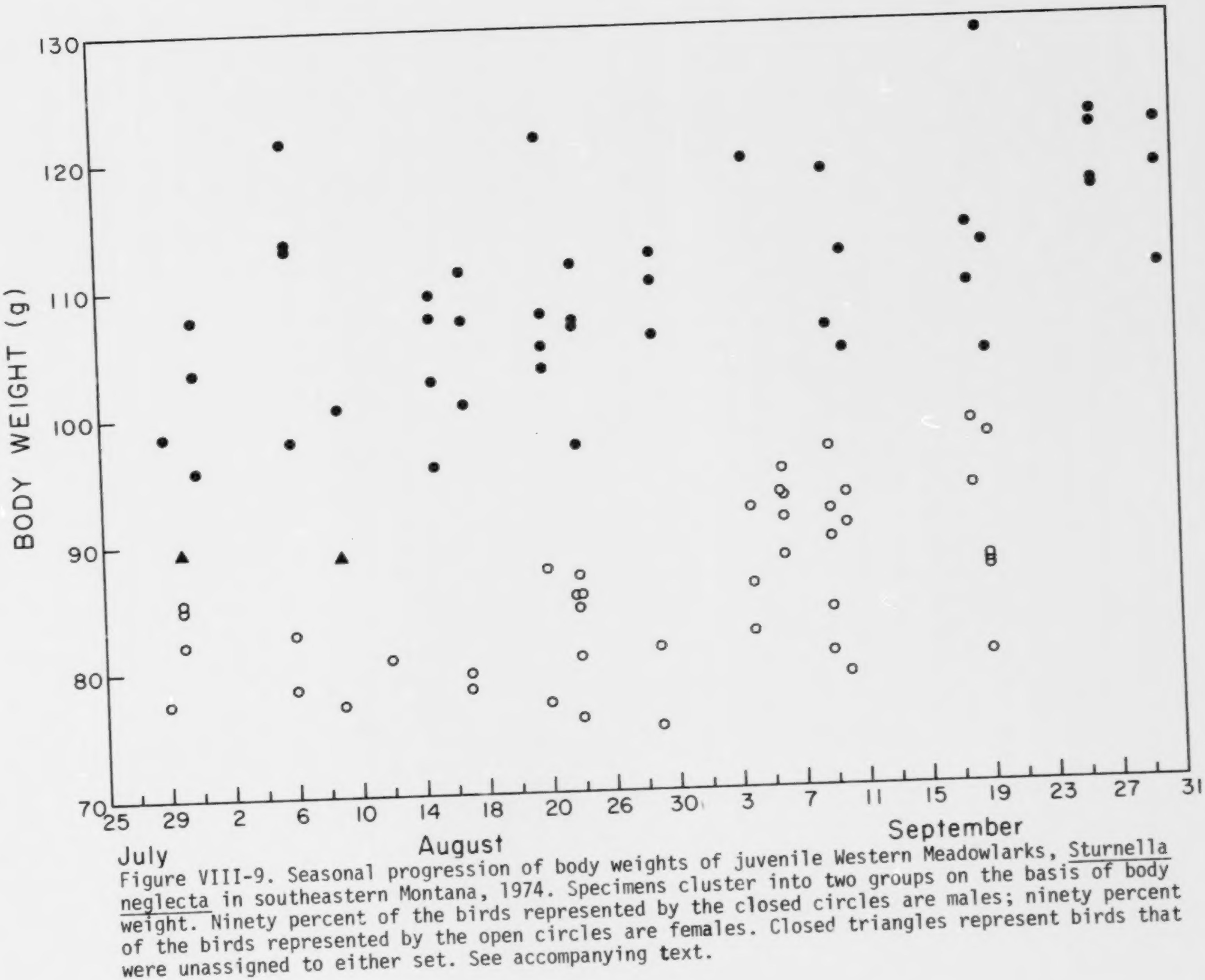


Figure VIII-9. Seasonal progression of body weights of juvenile Western Meadowlarks, Sturnella neglecta in southeastern Montana, 1974. Specimens cluster into two groups on the basis of body weight. Ninety percent of the birds represented by the closed circles are males; ninety percent of the birds represented by the open circles are females. Closed triangles represent birds that were unassigned to either set. See accompanying text.

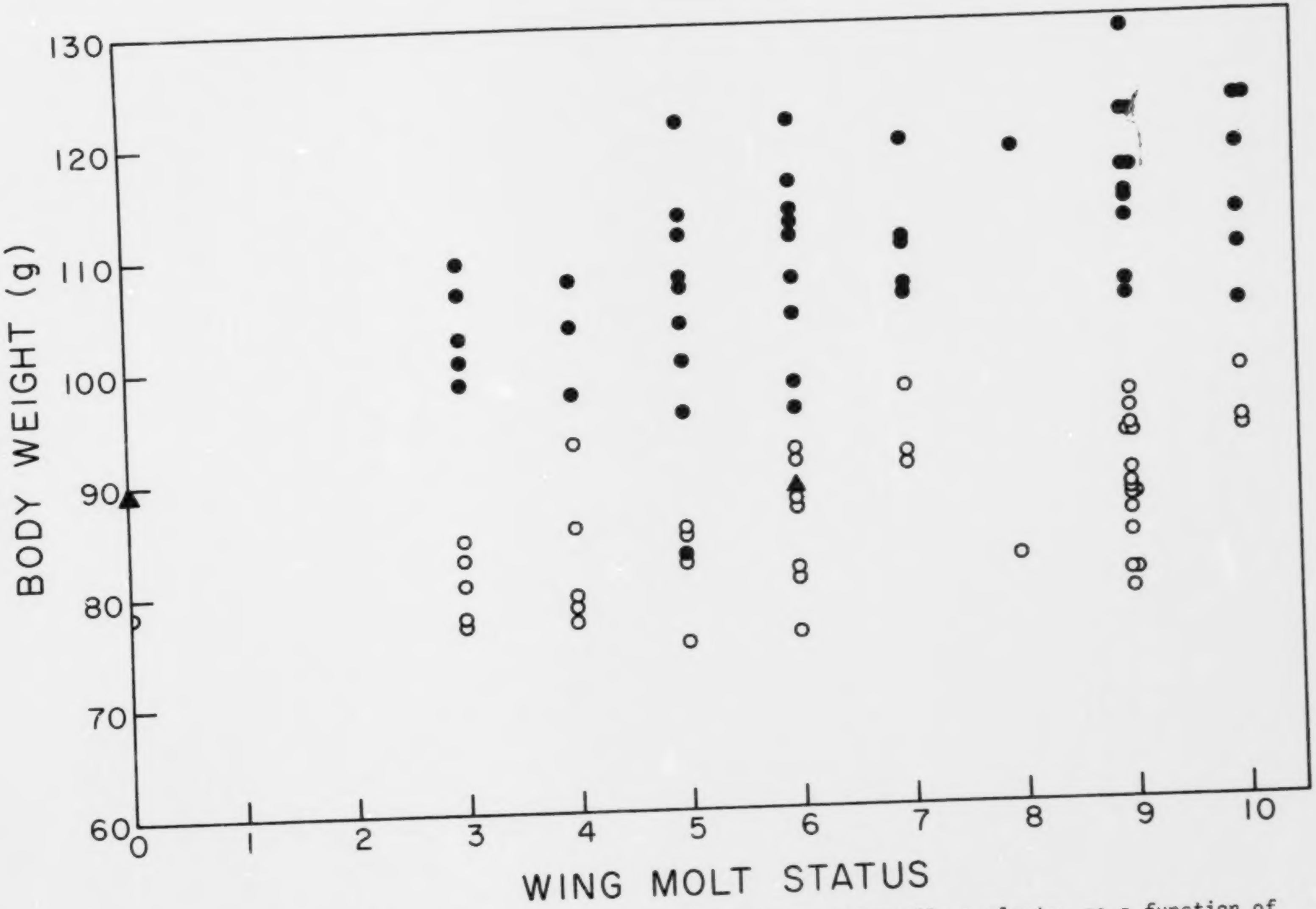


Figure VIII-10. Body weights of juvenile Western Meadowlarks, *Sturnella neglecta*, as a function of molt stage. Stage 0 is prior to onset of postjuvenal molt; stages 1 through 9 represent the highest primary feather that is growing; and stage 10 represents birds in which the molt is complete. Molt proceeds sequentially from 1 through 9. Specimens cluster into two groups on the basis of body weight. Ninety percent of the birds represented by the closed circles are males; ninety percent of the birds represented by the open circles are females. Closed triangles represent birds that were unassigned to either set. See accompanying text.

Figure VIII-11. Progression of postjuvenal molt of Western Meadowlarks, Sturnella neglecta in southeastern Montana, 1974. See Figure VIII-10 for definition of molt stages. Closed circles represent males; open circles, females.

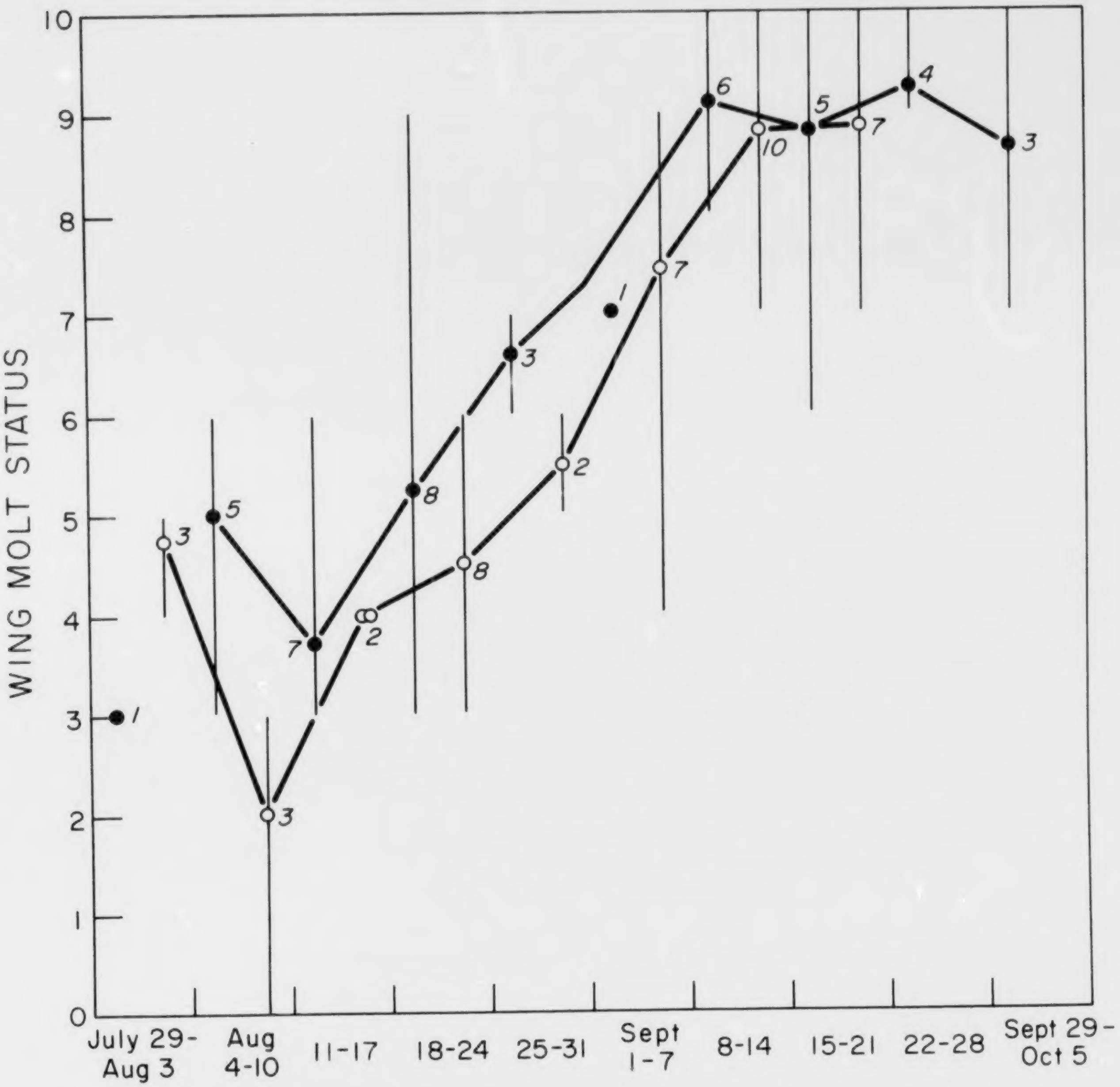


Figure VIII-12. Weight of the dried integument (plumage and skin) of juvenile Western Meadowlarks, Sturnella neglecta, during the period of postjuvenal molt (see accompanying text). Closed circles represent males; open circles, females.

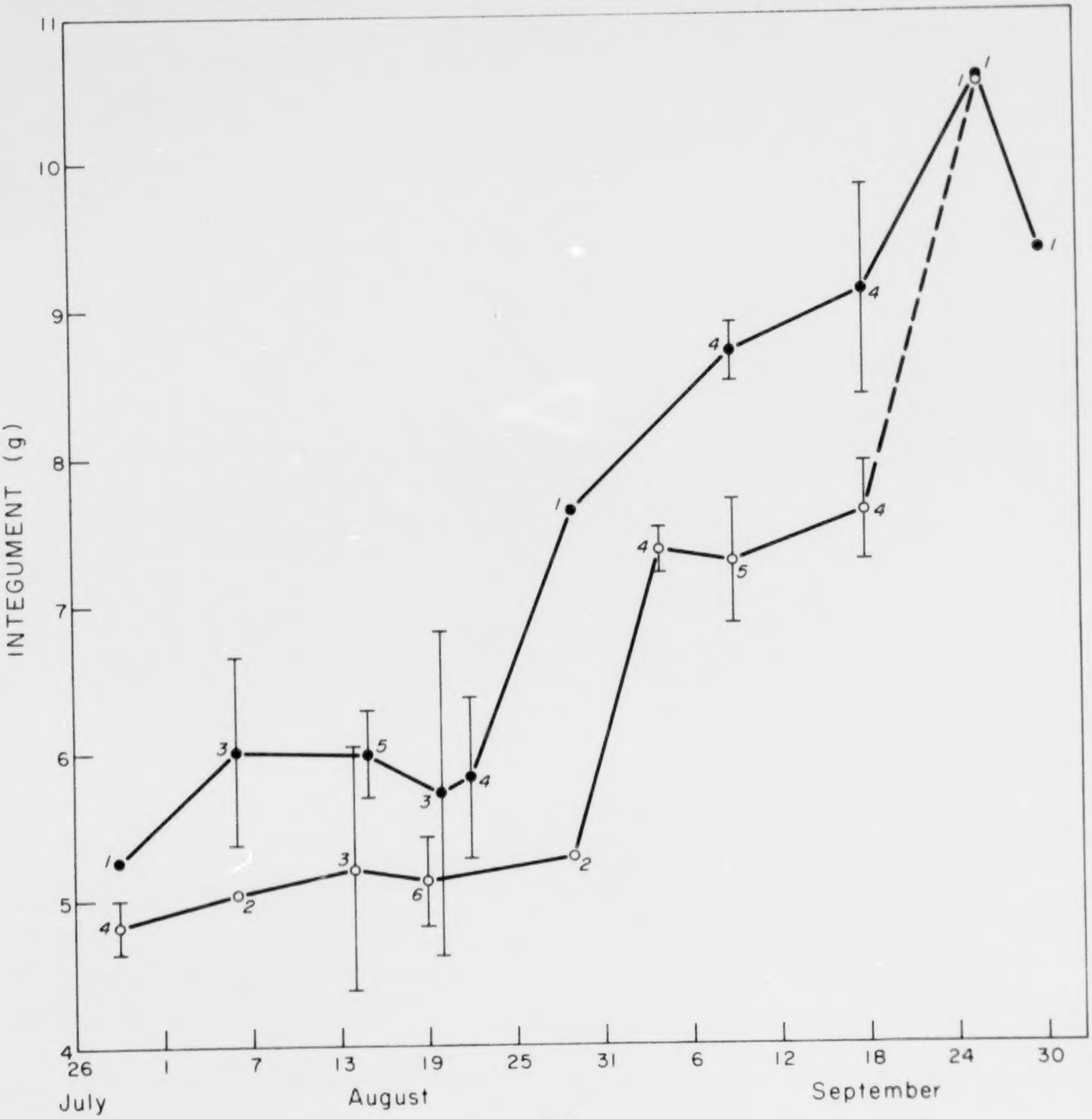


Figure VIII-13. Weight of the dry carcass (less plumage and skin) of juvenile Western Meadowlarks, Sturnella neglecta, during the period of postjuvenal molt. Closed circles represent males; open circles, females.

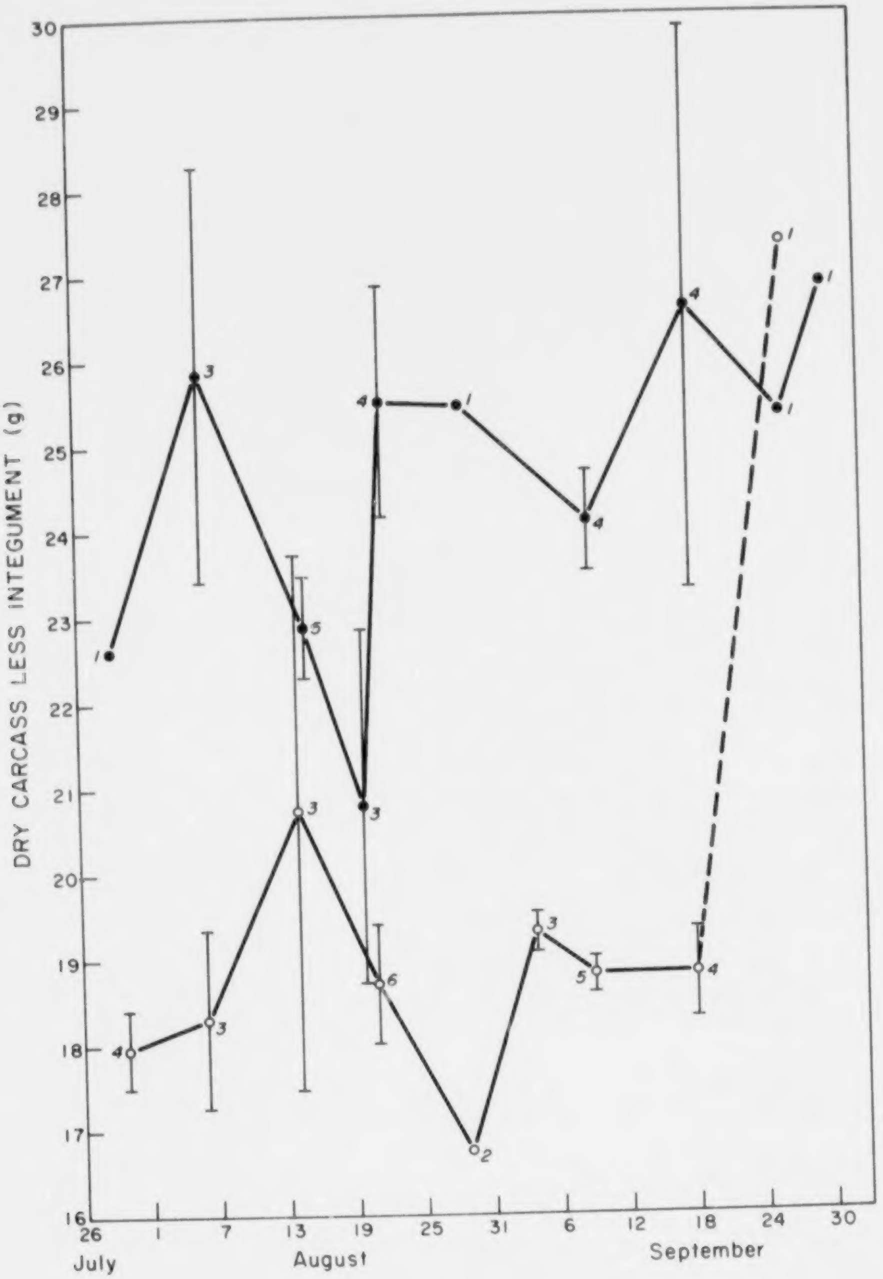


Figure VIII-14. Weight of the dry carcass (less plumage and skin) of juvenile Western Meadowlarks, Sturnella neglecta, as a function of molt stage. See Figure VIII-10 for definition of molt stage. Closed circles represent males; open circles, females.

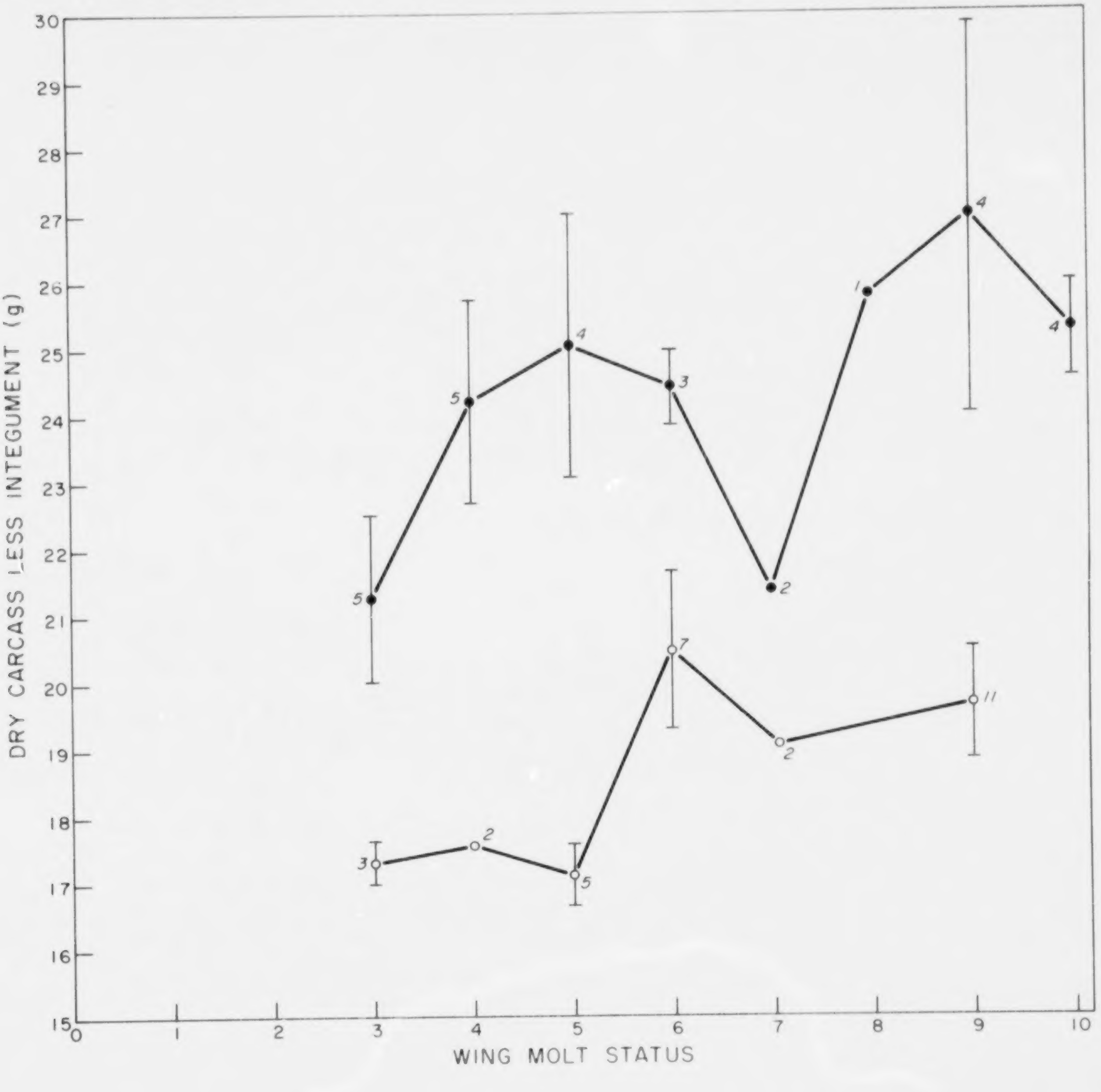
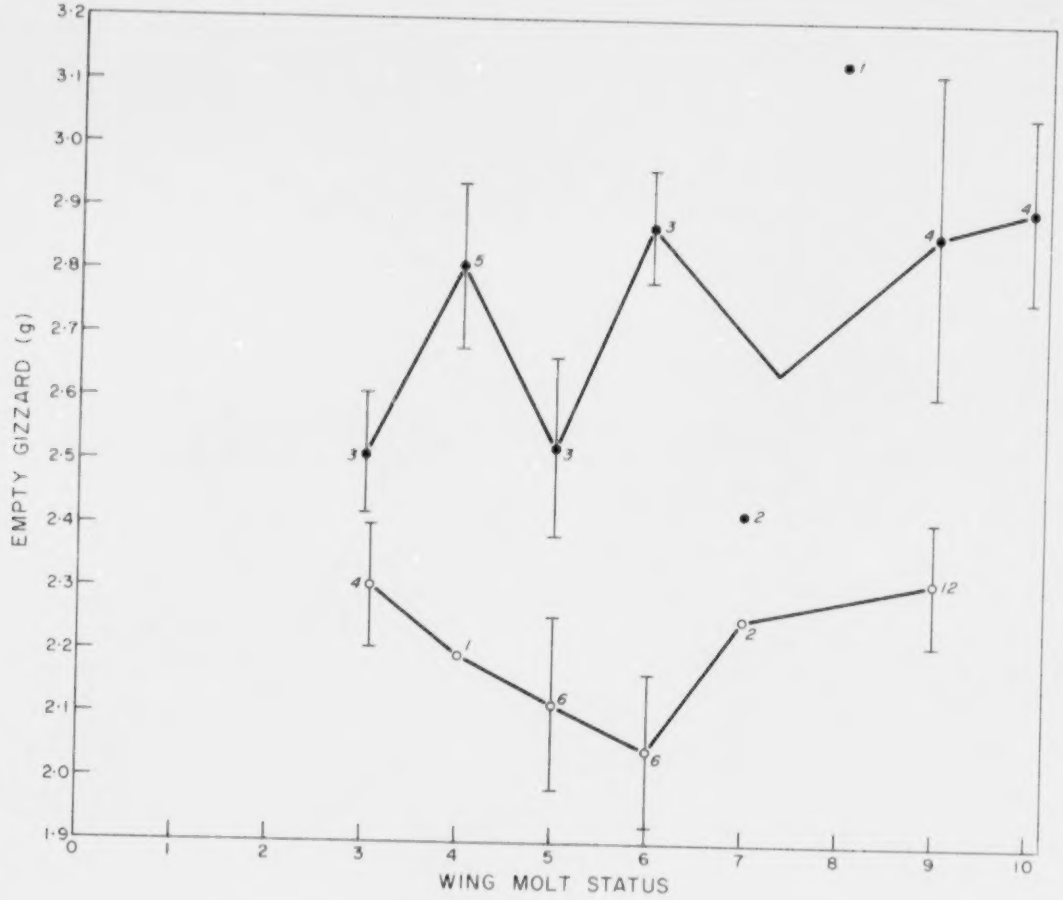


Figure VIII-15. Weight of the gizzard of juvenile Western Meadowlarks, *Sturnella neglecta*, as a function of molt stage. See Figure VIII-10 for definition of molt stage. Closed circles represent males; open circles, females.



gizzard to increase during periods of increased food intake. Our analysis is complicated because the Meadowlarks under consideration are growing and because we have not yet analyzed the stomach contents of these birds (i.e., harder food as well as increased rate of intake might produce hypertrophy). Nevertheless, gizzard weight increased substantially in males during the course of molt and development, but not in females (Figure VIII-15). There was a corresponding increase in the bulk of the stomach contents of males. This presently incomplete data set indicate that food resources (1974) are utilized differently by males and females during the period of postjuvenal molt; they are perhaps less efficiently exploited or processed by the females.

Both the thymus and the bursa of Fabricus (Figure VIII-16) of the Western Meadowlark, Sturnella neglecta, persist for an as yet undefined period following the assumption of the winter plumage. This allows us to easily distinguish adult birds and birds of the year at least throughout the fall. We are thus, for example, hoping to determine when birds of the year reach adult size and condition. Some observations indicate that the thymus is still evident in adult females (but not males) during the early part of at least their first breeding season.

Both the thymus and bursa of Fabricus are of special concern to us because some air pollutants act as immunosuppressive agents; such effects might be reflected in the development and activity of these glands.

Ancillary to the vertebrate animal research and as an aid to the establishment of pollution gradients, we are studying the corrosive effects of the atmosphere at the 18 sites depicted in Figure VIII-17. Four 4x3 inch steel plates are suspended by plastic ties from fences at each of these sites. The plates are made of low carbon (200-400 ppm), low copper (300-500 ppm) steel, Armco enameling iron DO plate. Each set of plates is exposed for a period of three months. The plates are

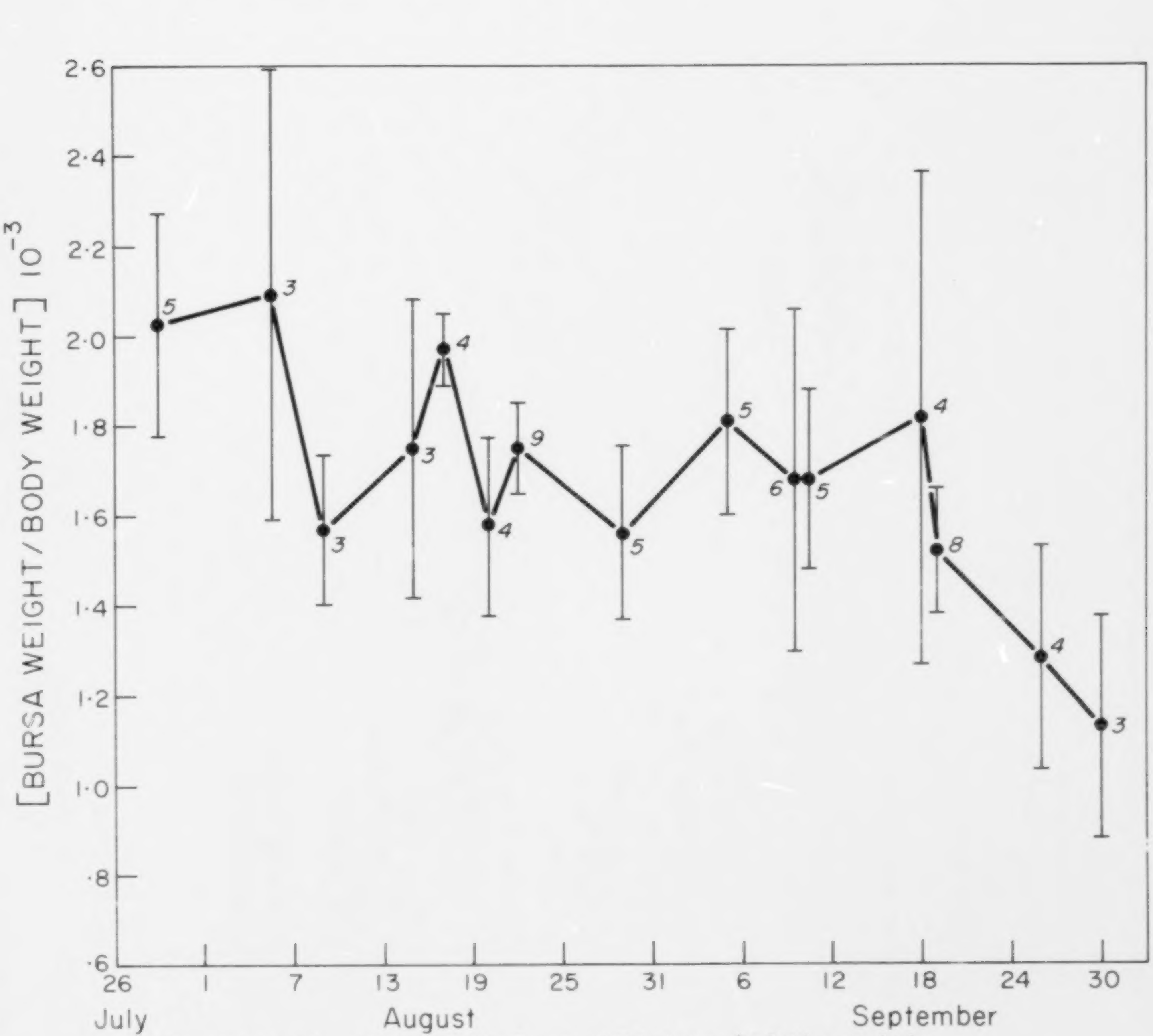
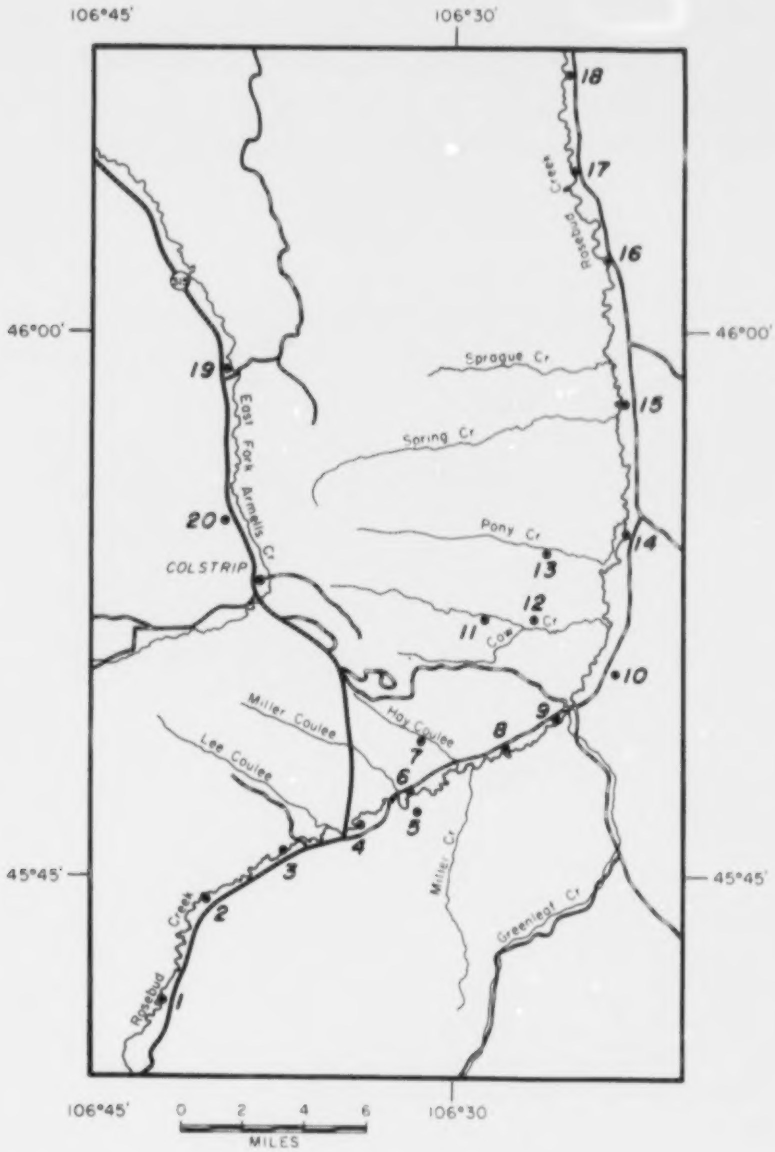


Figure VIII-16. Weight of the Bursa of Fabricius (relative to body weight) of juvenile Western Meadowlarks, Sturnella neglecta, during the period of postjuvenal molt. The data for males and females are grouped.

Figure VIII-17. Map of sites employed to study corrosiveness of the atmosphere.


106°45'
106°30'
46°00'
45°45'
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18
19
20
COLSTRIP
East Fork Armells Cr
Rosebud Creek
Sprague Cr
Spring Cr
Pony Cr
Cow Cr
Hay Coulee
Miller Coulee
Lee Coulee
Miller Cr
Greenleaf Cr
0
2
4
6
MILES

cleaned by a standard method before exposure, and are dried and weighed to the nearest milligram on the day prior to exposure. Following exposure, the plates are again carefully cleaned and reweighed. Corrosion rate is expressed as the number of milligrams lost per day per square decimeter of exposed surface. It is too early to evaluate the results of this study on a site-by-site basis. During the autumn quarter of 1974, mean rate of corrosion was 0.49 (S.E.M. = 0.03) mg/day-cm^2 and during the winter quarter, the corresponding values were 0.59 (±.03).

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SECTION IX

THE FIELD EXPERIMENTAL COMPONENT: EVALUATION OF THE ZONAL AIR POLLUTION SYSTEM

by

Jeffrey J. Lee, Robert A. Lewis, and Denis E. Body

INTRODUCTION

The field experimental component of this investigation is sited on a grassland park in Custer National Forest in Southeastern Montana. Experimental challenge of four one-acre plots with sulfur dioxide was initiated in May, 1975. The plots are situated within a 27-acre exclosure to protect livestock from injury and to protect equipment from livestock damage.

These experiments are designed to test the effects of SO_2 upon plant and animal (arthropods) biomass dynamics; plant community structure; insect and fungal diseases of plants; pollination systems; lichens; and upon a number of physiological and biochemical functions. Dominant plants on the study plots are Western wheatgrass (*Agropyron smithii*), prairie junegrass (*Koelaria cristata*), and Sandberg bluegrass (*Poa secunda*).

The system was designed to allow us to maintain a different constant 30-day median concentration on each plot during the growing season (ca. 1 April-30 September). Continuous monitoring of gas concentrations will ensure that the desired levels are maintained. Application of a Gaussian dispersion model (Turney, 1969) indicates that, under *unfavorable* dissipation conditions, concentrations about 200 feet from a 40 pphm plot will remain below 5 pphm. Thus, at the concentrations employed (Table IX-2), the effects on surrounding areas will be minimal and

Table IX-1. GEOMETRIC MEANS (GM) AND STANDARD GEOMETRIC DEVIATIONS (SGD) OF ATMOSPHERIC SO_2 (PARTS PER HUNDRED MILLION) FOR URBAN AREAS. FIVE MINUTE AVERAGES. (HOLZWORTH, 1973. PP. 162-67).

City	GM	SGD
Chicago	10.4	2.2
Cincinnati	1.6	2.9
Denver	1.3	2.1
Los Angeles	1.3	2.3
Philadephia	5.5	2.4
St. Louis	2.8	2.8
San Francisco	0.5	2.9
Washington	3.9	2.2

significant levels will not occur outside the study enclosure. A log-normal distribution of concentrations about the mean is both expected and desired since this distribution pattern is typical of gaseous industrial pollutants. Preliminary testing of a prototype system during September 1974 indicated the feasibility of this type of control.

DESIGN REQUIREMENTS

The ultimate design goal was to provide a system for well-defined assessment of the sulfur dioxide impact on otherwise undisturbed grassland ecosystems. We have approached this ideal by establishing realistic ecological and physical criteria.

Disturbance of biota and of micro-climates by the gas delivery system must be minimized. Effects on incident radiation, prey refuges, ground level obstructions and pathways, temperature, humidity, wind, and other features of the micro-habitats must be kept as small as possible. The area to be gassed must be large, on the spatial scales of the populations to be sampled, to reduce edge effects and to assure adequate population and sample sizes. Areas chosen for comparisons (i.e., treatments and control) should be as uniform as possible in habitat, edaphic and terrain features.

The distribution of pollutants must meet certain spatial and temporal constraints. Concentration should follow a log-normal distribution similar to those which occur in polluted areas (Holzworth, 1973). The distribution should be spatially uniform or nearly so, at least on a time average basis. Specifically, there should not be any "hot" or "dead" spots and concentrations must be controllable for a range of selected averages. Finally, cost, maintenance and operation must be reasonable.

The system that we have designed meets these criteria. Each study plot has a 1 1/4 acre network of one-inch pipe supported above ground level by pipe stakes. The centers of the plots are located along a line, with buffer zones between plots wide enough to prevent interference. A dilute mixture of air and SO_2 flows through the lines and is released at numerous points over the grid.

The only ground-level obstructions within the plots are the supports. These should present minimum interference with animal movements while the pipe network should cause minimum impact on micro-climate. The relatively small size of the plots will exclude the study of large animals. However, insects and other arthropods will be included. In addition, the areas between plots can be studied, although under less easily evaluated conditions, permitting a limited study, perhaps, of small rodents. The contiguity of the plots allows for nearly uniform habitat conditions.

By utilizing many small, elevated point sources, adequate dilution of SO_2 at ground level is ensured and, in effect, an area source is created. This prevents step-function changes in concentrations in time and space. Testing of the system confirmed our expectations regarding the nature of the distribution.

PROTOTYPE TESTING

A full scale prototype of the Zonal Air Pollution Systems (ZAPS) was constructed and employed to test the feasibility of this approach (Lee and Lewis, 1975). Analysis of the data obtained from the prototype and the progress made toward application of the multiple plot system are discussed in the following sections.

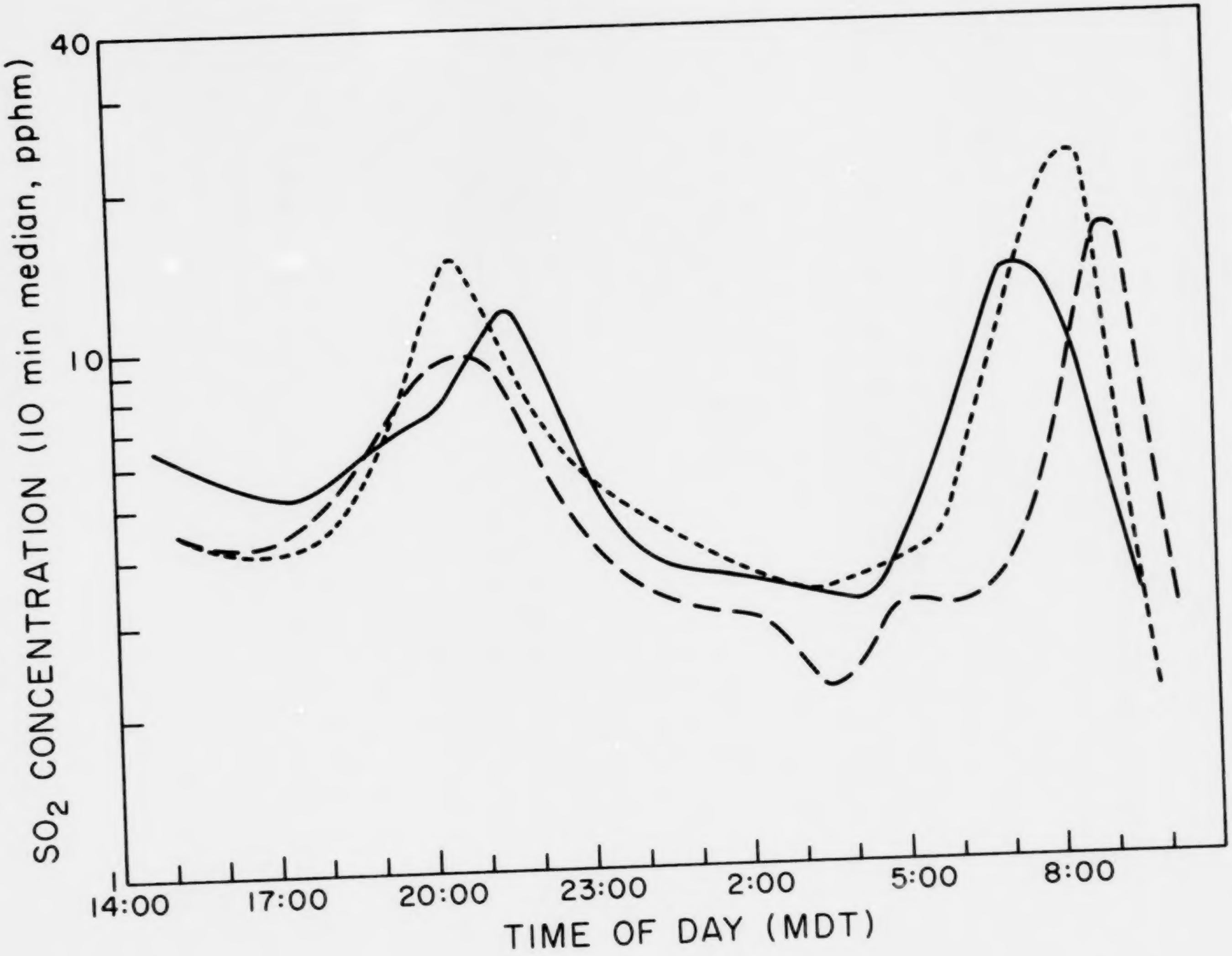


Figure IX-1. Distribution of concentrations on the prototype.

PROTOTYPE: DATA COLLECTION

Sulfur dioxide was monitored by recording the output of a sulfur analyzer in the logrythmic mode. Eight sample lines fed into a time-share device so that each line was sampled for 10 of every 80 minutes. The ends of four of the lines were moved to various positions within the plot, while one line always sampled the center of the plot. The remaining three lines were placed adjacent to the plot near the equipment shed. All sample points were located approximately one foot above ground level.

Wind speed and direction were recorded frequently each day. The weather was generally clear and mild during the test period (October, 1974). Daily highs were in the 70's (Farenheit) with lows in the 40's.

PROTOTYPE DATA: TEMPORAL VARIATION

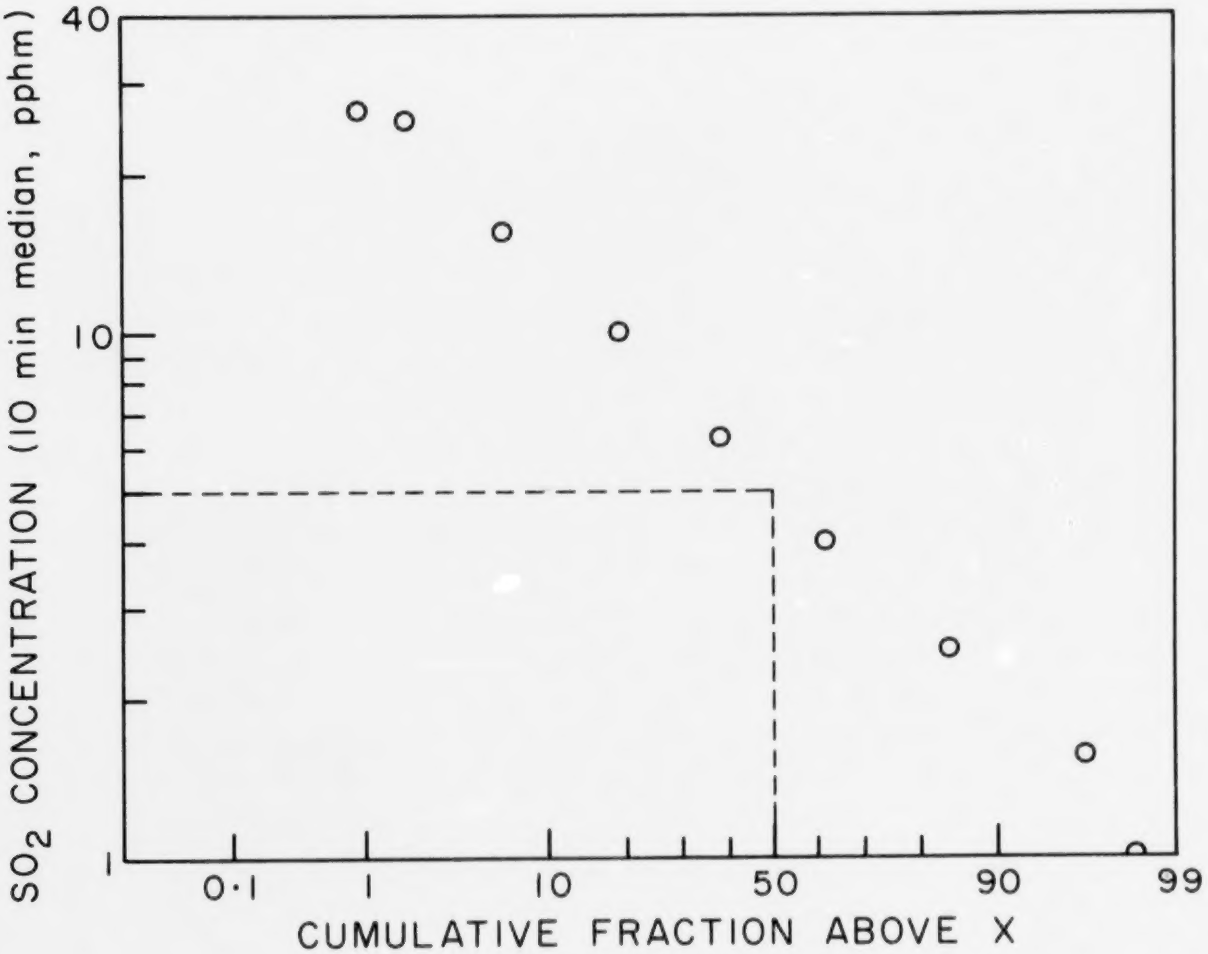
Data on the temporal variation of concentrations were obtained mainly from the central sampling point. In models of pollutant dispersion, source strength appears as a normalization constant with the patterns of distribution determined by meteorological conditions (HEW, 1970). The frequency distribution of concentrations of the central point was obtained by pooling all data from this point, after normalizing to the most common source strength (i.e., SO_2 flow rate). The results (Figure IX-1) clearly demonstrate that the concentrations were log-normally distributed with a geometric mean (GM) of 5.2 pphm, a standard geometric deviation (SGD) of 2.1, and an arithmetic mean of 6.5 pphm. Typical values for 5-minute averaging times of GM and SGD (Gilbert, 1970) are given in Table IX-1. Note the relatively low variability of SGD over a range of geometric means, reflecting the independence of SGD and source strength. The values obtained by the prototype are consistent with these data.

The main point is not that the system simulated a particular place (i.e., Philadelphia, 1962-1967, Table IX-1) but rather that the concentrations across the plots are adequately controlled at the low levels desired. Conditions within the plot mimic either locations subject to area sources or locations some miles down wind from point sources. Changes in average concentrations associated with changes in wind direction from a point source can be simulated simply by adjusting the SO_2 flow rate.

Typical time series for the central and two other sampling points, located near opposite corners of the plot, are shown in Figure IX-2, which contains only un-normalized data. The main features are the two peaks, one near sunrise, and the other after sunset. The three sample points generally track one another although some phase differences are evident.

Diurnal patterns of pollutant SO_2 concentration from both stationary point sources and in urban environments are frequently similar to that produced by our system (Holzworth, 1973; Le Quinio, 1973; Raynor, Smith and Singer, 1974; Smith, 1968; Saito and Mizoguchi, 1973). Such variation in air pollutant concentrations are due to (a) variations in source strengths that, in turn, may result from daily cycles in human activity (Garnett, 1973; Holzworth, 1973); (b) transport wind speeds and directions, atmospheric diffusion, and interactions (Cormier, 1974; Fukuoka, 1973; Garnett, 1973; Holzworth, 1973; Lomaya and Tsintsadze, 1974; Martin, 1974; Smith, 1968). All of these vary as a function of weather and season (Balabuyev, Lomaya, and Tsintsadze, 1973; Druilhet and Fontan, 1973; Fukuoka, 1973; Sandig and Saendig, 1973). Atmospheric dilution is frequently greatest during the day and least at night. This may result in one or more daytime minima and a nocturnal maximum in pollutant concentrations (Holzworth, 1973).

Figure IX-2. Time-series of concentrations on proto-type, October 12, 1974. Points are center (-----), generally upwind (------), and generally downwind (______). Latter two were nearer the lines than the central point.



PROTOTYPE DATA: SPATIAL VARIATION

Concentrations varied systematically and smoothly over the plot. Regions near the delivery lines tended to exhibit values up to three times higher than regions midway between the lines (Figure IX-2), although there did not seem to be any "hot spots" associated with the release points. Concentrations generally increased in the direction of the prevailing wind and decreased at a moderate rate outside the plot proper so that concentrations 20 to 50 feet beyond the plot border were comparable to those within the plot.

PROGRESS TOWARD APPLICATON OF THE SYSTEM

At this writing, the first set of Zonal Air Pollution Systems employing the modified delivery geometry (Lee and Lewis, 1975) and treatments have begun. We expect to deliver SO_2 continuously throughout the remainder of the growing season. Ideally, treatments should begin in the spring when the 10-day running average of air temperature exceeds 5.0°C and terminate when the 10-day running average falls to 5.0°C. The reason for this criterion is based on observations in the literature that plants with the C_3 Calvin-Benson pathway of CO_2 fixation can be quite active at 5°C. The dominant plants on the fumigation site are C_3 species. The rationale behind the 10-day moving average is simply to ensure that we will be neither beginning nor ending fumigation in response to brief periods of unseasonal weather. In a typical year, we expect to fumigate from about mid-April through October.

Based upon our estimates of the daily and seasonal variation in SO_2 concentrations to be expected from ZAPS and best guesses on the effects of peaks-biota interactions, we propose to maintain the median concentrations indicated in Table IX-2. Preliminary data from this spring indicate that the expected daily peak-median ratios are being attained.

Table IX-2. EXPECTED SO_2 CONCENTRATIONS (PPHM) ON THE FIELD EXPERIMENTAL PLOTS

Plot	5-Minute Median	Daily 3-hour Peak	Probable Growing Season Peak	Possible Seasonal Peak
1	0	0	0	0-2
2	2	8-10	15-20	90-100
3	5	20-25	40-50	100-200
4	10	40-50	100-200	400

With this design, we anticipate measurable, identifiable SO_2 effects on the plot with the highest concentration. SO_2 levels on this plot will frequently approach or exceed the present secondary standard of 0.50 ppm (1300 $\mu g/m^3$). This is the maximum 3-hour concentration that is not to be exceeded more than once each year. We feel reasonably confident that biological effects will occur at the 5 pphm median level (Elfimova and Guser, 1969; Gilbert, 1970; Palm, Nick, Arnold and Platy, 1973; Shalambergidye and Tseretli, 1971), and liminal effects might be seen as low as 2 pphm.

FUTURE APPLICATIONS

Construction of a second set of four ZAPS at the same site is planned. Procurement of the necesary materials is under way. Based on the experience gained thus far in ZAPS construction, we anticipate no problems in getting the second set operational by the start of the 1976 growing season.

ACKNOWLEDGEMENTS

Technical assistance in the operation of the prototype system was provided by Mr. Larry Doe.

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SECTION X

A REMOTE SENSING STUDY OF THE BIOENVIRONMENTAL EFFECTS OF STACK EMISSIONS FROM THE COLSTRIP, MONTANA, POWER PLANT

by

Thomas R. Osberg, Robert A. Lewis, and John E. Taylor

INTRODUCTION

As a key integrative element of the Montana Coal-Fired Power Plant Project, we are developing and applying remote sensing as a tool to (a) detect biological effects of air pollutant challenge; (b) measure inventory loss that results from strip mining, installation of power lines, increased human activity, water use and other potentially confounding influences such as pesticides, disease, and population cycling; and (c) aid in the development of predictive models.

We expect this remote sensing task to provide data that confirm and extend the information gained from ground-based studies. High resolution camera systems installed in both high performance, high-altitude aircraft and in low-flying craft should provide an excellent permanent temporal record of the study areas. Repetitive coverage of a particular ground area or target is an established technique (Colwell, 1968) for detecting changes in both natural and man-made features (Genderen, 1974; Pollanschuetz, 1968; Zealear, Heller, Norick, and Wilkes, 1971) and has been applied in some instances to the evaluation and management of grassland resources (Carneggie and Reppert, 1969; Carneggie, 1970; Poulton, 1970) and in the assessment of terrestrial effects of air pollution from coal-conversion facilities (Genderen, 1974; Pollanschuetz, 1968; Zealear, Heller, Norick, and Wilkes, 1971). In at least some instances color infrared photography detects plant injury from air pollutants prior to visual registration (Bravo, 1972) or reveals non-visible injury that may be associated with decreased growth and yields (Pollanschuetz, 1968). Thus, remote sensing as applied to this study offers a predictive potential.

We are evaluating several photographic processes (color, color IR, and monochrome) at varying scales (1:2000 to ERTS) as tools for the assessment of air pollution impact from the power plant at Colstrip, Montana, and the effects of SO_2 on our field experimental plots on Custer National Forest in Southeastern Montana. Work thus far has shown that 70 mm color at a negative scale of 1:3000 yields sufficient resolution for most vegetation work. During 1974, project work was primarily developmental; now we are prepared to apply the most appropriate procedures to biological effects monitoring (Taylor, Leininger, and Fuchs, 1975).

The high-altitude photography ranged in scale from 1:35,000 to scales in excess of 1:80,000. High-altitude photography provides synoptic coverage and is most suitable for analysis of natural features in large areas, as well as for mapping purposes. Conversely, low altitude flights yield imagery with scales to 1:500. This photography is essential in obtaining detailed information of selected small targets on the ground.

A series of three to six low level flights is planned for 1975. These will be timed to coincide with key periods of the growing cycle. Color and color infrared emulsions will be used. The sensor system, consisting of two Hasselblad cameras, yields a frame format of 70 millimeters. Although this is relatively small, we expect to acquire photography at scales as large as 1:2000. We believe that sufficient detail can be seen in this imagery to enable us to trace and describe pollution stress patterns that develop in grasses and other types of vegetation discernible in the imagery. This large-scale imagery will be used for repetitive coverage of the field sites. Information from this source, in conjunction with ground data obtained in the field, should aid the overall program in assessing microclimatic and air pollution patterns and effects.

The high-level photography will provide baseline data for vegetation and landform mapping, including a seasonal record of vegetational community composition. Information on microclimates and moisture gradients is also desired, including records of subirrigated and run-in moisture areas, erosion (if any), snow melt patterns, and drainage patterns. We hope also to record infrared signatures of individual plant species and plant communities. These photographs will provide information on grazing patterns, winter game use, and the number and dispersion of large game.

The low-level (500 feet) photography, with more detailed information on specified sites, should bridge the gap between high-level and ground-level records. Early in the program we acquired imagery of the Colstrip area from four high-altitude missions. All photographs from these missions, taken during summers of 1972, 1973 and 1974, are color infrared. Combined, they cover more than 10,000 square miles around Colstrip. This photography represents an important source of baseline information prior to operation of the power plant. The photography was loaned to EPA; the photolab at the Environmental Photographic Interpretation Center (EPIC) duplicated the films. Table X-1 summarizes the coverage information.

In 1975, the National Aeronautics and Space Administration will make two high-altitude flights. Both color and color infrared films with nine-inch frame format will be used. Coverage is planned for a one degree cell: 46 to 47 degrees north by 106 to 107 degrees west (Figure X-1). It includes the power plant and mines at Colstrip and the sites located east and southeast of Colstrip. The missions are scheduled for early May and mid-summer to coincide with critical periods of the growing season. A nominal scale of 1:40,000 is expected from this high altitude photography.

Field study sites for the program have been established at two general locations near Colstrip. Some six study sites are situated within a 20 kilometer (12 miles) arc to the east and south of the power plant (Figure X-2). A group of three sites is situated near Fort Howes Ranger Station, about 75 kilometers (47 miles) from Colstrip (Figure X-3). Experimental fumigation of grassland communities will be conducted on the three sites (about 25 acres each). A major goal of the remote sensing work is to record stress patterns that occur at the field experimental sites over a protracted period.

ACKNOWLEDGEMENTS

Photographs from the four high-altitude overflights of the Colstrip region were acquired within the past three years by other Federal agencies based in Billings. We want to acknowledge the efforts of the people responsible for loaning this invaluable imagery. Fred Batson and Ed Zaidlicz, U. S. Bureau of Land Management, Montana office, provided coverage of two BLM resource areas Rosebud-Coalwood and Birney-Decker. Paul Kipp and Keith Beartusk, Bureau of Indian Affairs, Billings and Lame Deer, made available photos of Indian lands near Colstrip; and the U.S. Forest Service in Billings furnished photographs of the Custer National Forest.

Table X-1 HIGH ALTITUDE PHOTOGRAPHY OF SOUTHEASTERN MONTANA

Area of Coverage	Date	Scale	Originating Agency
Rosebud-Coalwood Planning Unit	28 June 1974	1/80,000	Bureau of Land Management, U.S. Department of Interior
Decker-Birney Planning Unit	1 June 1972	1/40,000	Bureau of Land Management, U.S. Department of Interior
Northern Cheyenne Eastern One-Third of the Crow Indian Reservations	4-5 July 1973	1/40,000	Bureau of Indian Affairs, U.S. Department of Interior
Custer National Forest Ashland/Fort Howes District	28 August 1973	1/36,000	U.S. Forest Service, U.S. Department of Agriculture

TOTAL AREA: Over 10,000 square miles or 2,590,000 hectares

Figure X-1. The Colstrip Power Plant is Based on an Extensive Supply of Coal Reserves in the Fort Union Deposit of the Great Plains. Over 10,000 square miles of area surrounding the plant has been photographed by high altitude camera systems since 1972. Map scale 1/500,000.

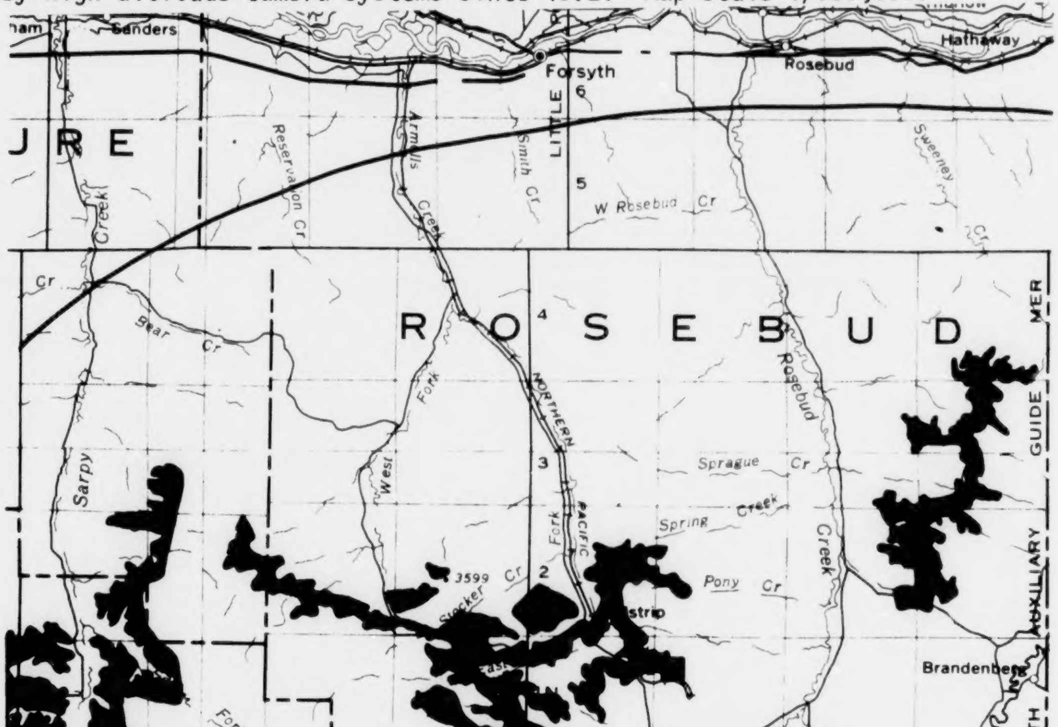
Sanders
Forsyth
Rosebud
Hathaway
ROSEBUD
Reservation Cr
Armells Creek
Smith Cr
W Rosebud Cr
Sweeney Cr
Bear Cr
Sarpy Creek
West Fork
NORTHERN PACIFIC
Sprague Cr
Spring Creek
Pony Cr
Rosebud Creek
Colstrip
Stocker Cr
Brandenberg
11TH AUXILIARY GUIDE MER
38
39
41
42
43
1S
Little Wolf Mts
Lynch Coulee
Indian Coulee
Rye Grass Cr
Garfield Pk
Badger Peak
Lame Deer
Lame Deer Cr
Lay Cr
Muddy Cr
GUIDE MERIDIAN
Logging
Fisher Butte
4396
Busby
W Fk
Davis Cr
E Fk
Kelty Cr
King Mtn
River
Trail Cr
Rosebud
S Fk
Creek
O'Dell

Figure X-2. Aerial Photograph of the Area Immediately to the East and South of the Colstrip Mines. A portion of the Mines is visible as white tone at the left margin. Stream valleys appear as dark-toned meandering features. Field study sites lie between the mine and Rosebud Creek, seen flowing from southeast to north through the center of the photo. Original scale 1/80,000. Acquired by US Bureau of Land Management 28, June 1974.

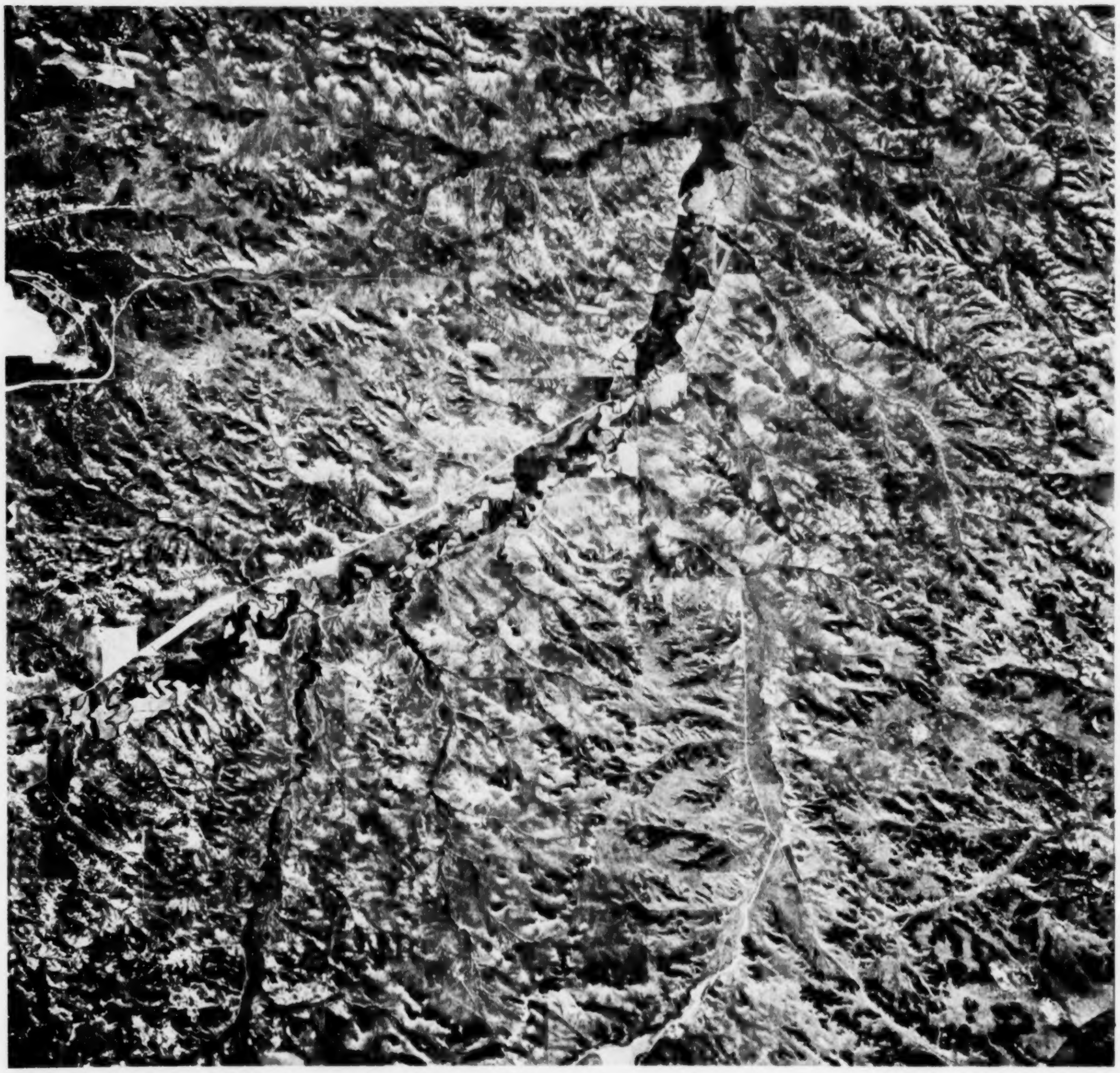

Figure X-3. Field Study Sites in the Vicinity of the Fort Howes Ranger Station are some 75 Kilometers South-Southeast of the Power Plant at Colstrip. Fort Howes is a small cluster of buildings north of the road intersection at the center of the photograph. Photography by US Forest Service, August 1973. Original scale 1/36,000.

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SECTION XI

AIR MONITORING CHARACTERIZATION AT THE HAY COULEE SITE, COLSTRIP, MONTANA

by

James R. Miller, T. Cail, Allen S. Lefohn

INTRODUCTION

The air monitoring characterization work is an integral component of the Montana Coal-Fired Power Plant Project designed to determine the effects of emissions from coal-fired power plants on the surrounding environment. A mobile laboratory was installed at Hay Coulee, about seven miles southeast of the Colstrip plant location. Measurements and tests were conducted during August, September and October, 1974.

EXPERIMENTAL

The mobile laboratory is equipped with the following instruments that measure various parameters of the ambient air. The outputs of the instruments described in points 1 through 4, below, are connected to a data acquisition system. This system uses a mini-computer that scans the instruments every five minutes and prints the data in engineering units as hourly and daily (24 hr) averages. The data are stored on magnetic tape.

1. Carbon monoxide (CO), methane (CH_4), and reactive hydrocarbons (total hydrocarbons less methane) are measured by a Beckman 6800 Air Quality chromatograph that uses a flame ionization detector to measure concentration as the compounds are eluted following separation by gas chromatography. CO is converted to methane prior to detection.

2. Nitric oxide (NO), nitrogen dioxide (NO_2), and total oxide of nitrogen (NO_x) levels are measured by a chemiluminescent analyzer. Ambient air is drawn into the analyzer where the NO reacts with ozone in the detector cell. Light generated by this reaction is measured by a photomuliplier tube. The resultant signal is transferred to a memory circuit. After the sample passes through a converter that changes the NO_x into NO, the signal is subtracted from the NO_x signal. The difference represents the NO_2 level. The three signals are then channeled into a recording device.

3. Ozone (O_3) and total sulfur (SO_x) are measured by photomultiplier tubes that detect the light generated by reactions in the detection cell of the instrument. In the O_3 analyzer, the light is generated by a chemiluminescent reaction between O_3 and ethylene. Light is generated in the SO_x instrument by burning sulfur-bearing compounds in a hydrogen-rich flame.

4. Wind speed and direction are measured with a high frequency tachometer and a 0-540° potentiometer. In addition solar radiation is determined by a silicon photovoltaic cell in a solar meter.

5. Particulates are measured on a 24 hour basis by a standard Hi-Vol sampler.

6. SO_2 and NO_2 permeation tubes and a cold cathode mercury vapor lamp that measures O_3 concentration are used to calibrate the appropriate instruments. The calibrations are verified by wet chemical analysis as described in the Federal Register (1971). A standard mixture of CO and methane is used to calibrate the Beckman instrument. The mobile laboratory also contains a gas chromatograph equipped with a data reduction system. This unit is used to identify hydrocarbons in the ambient air. The method is similar to that described by Rasmussen and Holdren (1972).

RESULTS AND DISCUSSION

Table XI-1 summarizes data obtained during the 1974 August-October sampling period. Of the 43 days that nitrogen oxide data were collected, there were 5 days where the daily concentration of NO averaged 20 μg/m^3 (2 pphm) or more; 5 days when the NO_2 daily concentration averaged 9 μg/m^3 (0.5 pphm) or more; and 2 days when the average for NO_x was 60 μg/m^3 (3 pphm) or over. The highest daily averages were 34 μg/m^3 (2.8 pphm) for NO, 13 μg/m^3 (0.7 pphm) for NO_2, and 62 μg/m^3 (3.3 pphm) for NO_x. The highest individual hourly average recorded for both NO and NO_x occurred September 8 at 2300 hours when the NO value was 60 μg/m^3 (5.15 pphm) and the NO_x value was 100 μg/m^3 (5.50 pphm). For NO_2 the highest hourly average value of 35 μg/m^3 (1.75 pphm) was recorded October 2 at 2100 hours.

Ozone data were collected for 51 days. The daily average exceeded 98 μg/m^3 (5 pphm) on a single day only. That occurred on September 19 when the value was 109 μg/m^3 (5.57 pphm). The highest individual hourly average recorded was 135 μg/m^3 (6.90 pphm) at 1800 hours September 18.

During the 42-day survey period, the highest average daily concentration of SO_x (17 μg/m^3) was recorded on September 11. The daily average equaled or exceeded 13 μg/m^3 (0.5 pphm) only on three days the daily average was equal to or greater than 3 μg/m^3 (0.1 pphm) on 12 days.

The highest individual hourly average (52 μg/m^3 = 2.0 pphm) occurred on September 17 at 0900 hours.

Methane, carbon monoxide and reactive hydrocarbon data were collected for 25 days.

Ambient Air Quality Data

Table XI-1. Number of Days Daily Average Equal to or Greater Than Indicated Values

Parameter	≥5pphm	≥ 4 pphm	≥3 pphm	≥2 pphm	≥1 pphm	≥ .5 pphm	≥.1 pphm	Total Days	Highest Value-Date	Primary Standard	Secondary Std.
NO	0	0	0	5	18	32	42	43	2.8 pphm Aug. 28 - Sept. 1	--	--
NO_2	0	0	0	0	0	5	42	43	.7 pphm Sept. 26	5 pphm	5 pphm
NO_x	0	0	2	8	25	41	43	43	3.3 pphm Aug. 28	100 $\mu g/M^3$	100 $\mu g/M^3$
O_3	1	10	35	47	51	51	51	51	5.57 pphm Sept. 19	8 pphm	8 pphm
SO_x	0	0	0	0	0	3	12	42	.66 pphm Sept. 11	14 pphm	10 pphm 50 pphm
	≥ 2.00 ppm	≥ 1.5 ppm	≥ 1.0 ppm	≥ 0.5 ppm	≥ 0.1 ppm	≥ 0.5 ppm	≥ -.01 ppm				
CH_4	1	19	23	24	25	25	25	25	2.08 ppm Sept. 5	--	--
CO	0	0	0	0	15	22	24	25	0.46 ppm Oct. 5	9 ppm 35 ppm	9 ppm 35 ppm
THC Less CH_4	0	0	2	4	11	16	21	25	1.25 ppm Sept. 26	0.24 ppm	0.24 ppm
	≥ 125 $\mu g/m^3$	≥ 100 $\mu g/m^3$	≥ 75 $\mu g/m^3$	≥ 50 $\mu g/m^3$	≥ 25 $\mu g/m^3$	≥ 10 $\mu g/m^3$	≥ 5 $\mu g/m^3$				
Hi-Vol Particulate	0	0	1	7	34	58	60	61	93.2 $\mu g/m^3$ Sept. 26	75$\mu g/m^3$ 260$\mu g/m^3$	60$\mu g/m^3$ 150$\mu g/m^3$

The highest average daily concentration of methane (1362 $\mu g/m^3$ = 2.1 ppm) occurred on September 5; only 1 day of the 25 exceeded 1310 $\mu g/m^3$ (2.0 ppm). The methane background is approximately 980 $\mu g/m^3$ (1.5 ppm) since 19 days had an average equal to or greater than that value.

The highest daily average of CO was recorded October 5, 0.53 mg/m^3 (0.46 ppm). Of the 25 days sampled, 15 had a daily average of at least 0.12 mg/m^3 (0.1 ppm). The highest hourly average value, 0.92 mg/m^3 (0.8 ppm), occurred October 5 at 0400 hours.

The daily average of the reactive hydrocarbon (total hydrocarbon less methane) exceeded or was equal to 655 $\mu g/m^3$ (1 ppm) 2 days out of the 25. The highest daily average, 820 $\mu g/m^3$ (1.25 ppm), was recorded September 26. The highest hourly average occurred on October 16 at 0900, 1700 $\mu g/m^3$ (2.6 ppm).

Particulate matter collected by the Hi-Vol sampler was recorded for 61 days. The highest value, 93.2 $\mu g/m^3$, was recorded September 26. Average value for the sampling period was 30.6 $\mu g/m^3$.

From August 22 through October 15, 1253 hourly averages of wind speed and direction were recorded (Table XI-2). Wind was predominantly from the west and northwest. Wind speeds of less than 1 mph are termed "calm" and usually occurred during early morning. The average wind speed ranged from 5 to 8 mph with gusts up to 30 mph. The highest hourly value recorded was 26 mph.

Temperature was measured for the 60-day period from August 22 through October 20, 1974. The highest hourly average was 99°F, recorded October 2 at 1700 hours. The lowest average was 21°F, recorded September 21 at 0600.

WIND DIRECTIONAL FREQUENCIES[1]

Table XI-2

Calm	N	NW	W	SW	S	SE	E	NE
19%	12%	16%	19%	8%	9%	4%	9%	4%

[1] Values are presented as percent of time that wind flows from each of eight compass points.

Hourly averages of incident solar radiation ranged from 0 to 1.56 calories per square centimeter per minute; the highest value was recorded on August 23 at 1300 hours.

Relative humidity was measured for 18 days from October 3, through October 20. The hourly average ranged from 15 to 86 percent. The highest value was recorded October 4; the low of 15 percent was recorded on 12 of the 18 days.

Average hourly concentrations of ozone, and nitric oxide, together with mean temperature and solar radiation for the period of August 22 through September 26 are presented in Figure XI-1.

Future Activities

Ambient air quality characterization work will continue throughout the 1975 growing season. Project staff anticipate that these data will be available by December, 1975.

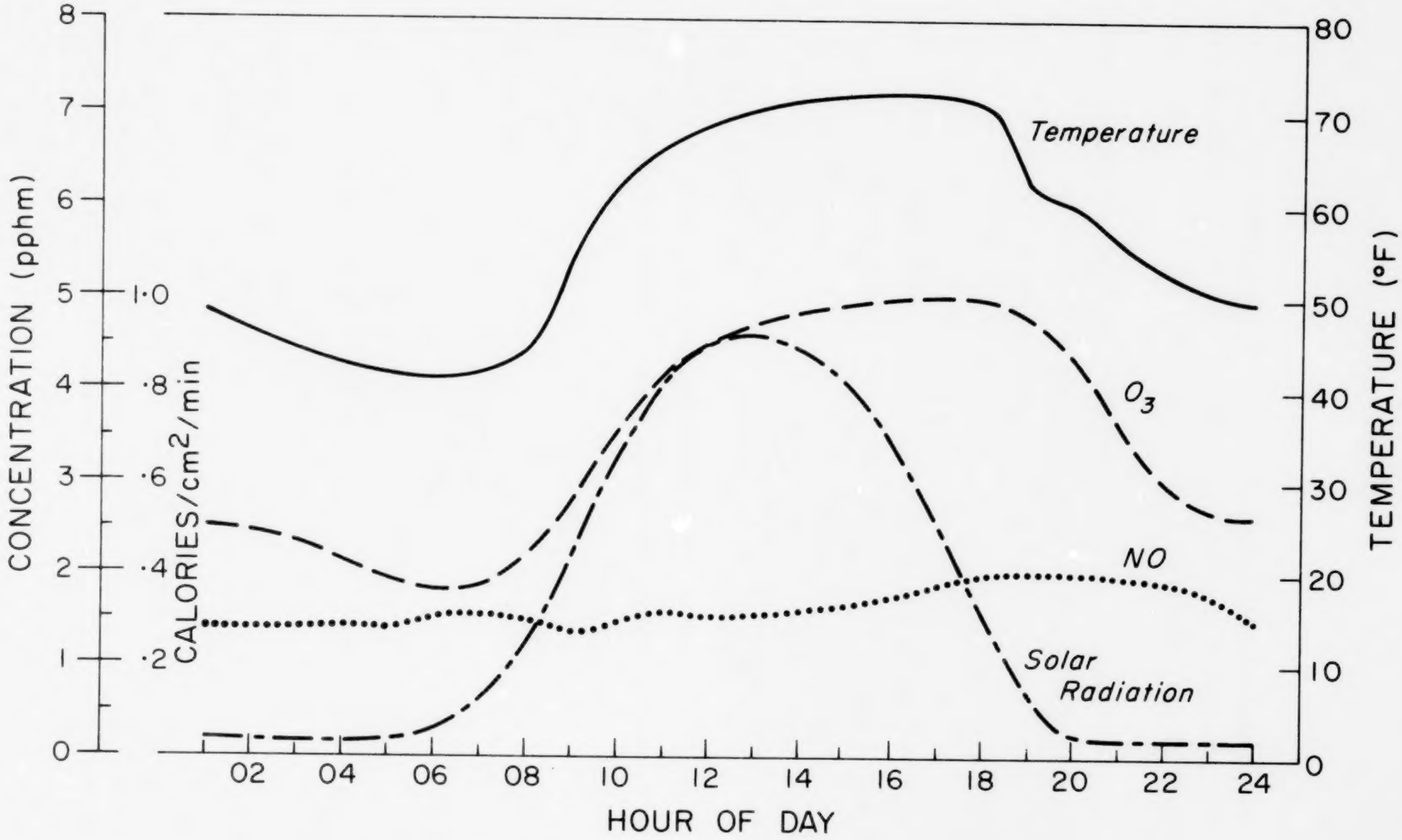

Figure XI-1. Comparision of Hourly Averages of Ozone, Nitric Oxide, Temperature and Solar Radiation.

References

1. Federal Register. 1971. Vol. 36, No. 84, Friday, April 30.

2. Rasmussen, R. A. and M. W. Holdren. 1972. Support-coated open tubular columns for trace analysis of air pollutants. Chromatography Newsletter. 1(2).

SECTION XII

INTEGRATED AEROSOL CHARACTERIZATION MONITORING

by

Vernon E. Derr, G. T. McNice and Allen S. Lefohn

INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) recently joined the National Ecological Research Laboratory's (NERL) research team on the Coal-Fired Power Plant Project at Colstrip, Montana. NOAA will provide integrated aerosol characterization monitoring of the area surrounding the Hay Coulee site. These data will be combined with the NERL air quality data to yield an integrated characterization assessment of the Colstrip site.

Assessment of particulate pollution requires measurements of aerosols, radiation, and meteorological conditions:

1. Particulates. Concentrations of particulates categorized by size, shape, and chemical constitution will be determined. Their effects on radiation and precipitation requires classification of condensation, ice, or Aitken nuclei (less than 1 μ). All measurements will be taken on the ground; some will be taken at heights great enough to observe the quantity of emitted material. The measurements will be collected by a combination of in-situ ground sampling, aircraft sampling, and lidar backscatter (ground based). To observe the geographical extent of stack plumes, aircraft lidar will be utilized.

A detailed description of the aerosol characterization facility and the lidar system is presented in Table XII-1.

2. Radiation Effects. Two radiation measurements are important. First, the rate at which solar energy reaches the earth as a function of wavelength will be measured (baseline) while the power plant is still inoperable. The changes registered during succeeding measurements while the plant is operating will be correlated with the particulate loading and changes in cloud cover. Also, by using aircraft and ground-based instruments, the earth's net heat loss will be determined with an infrared radiometer by measuring the upward and downward radiation. Infrared (IR) fluxes within and outside the plumes will be measured.

3. Meteorological Conditions. Meteorological variables will be measured by standard instruments. However, the meteorological conditions that tend to trap pollutants below temperature inversions are best measured by an acoustic sounder (Table XII-1).

An instrumented cloud physics trailer will be located on site. This trailer is equipped to take continuous measurements of Aitken nuclei (active at 300 percent supersaturation), cloud condensation nuclei (active at 0.1 percent supersaturation), aerosol light scattering, and standard meteorological parameters such as wind speed and direction, temperature, and humidity.

The in-situ elemental composition of individual aerosol particles will be derived from the real time output of a CO_2 laser spectrochemical analyzer. It operates by (1) decomposing the aerosol in the focal point of 50 watt 10.6 radiation; (2) exciting the atoms

Table XII-1
Aerosol Characterization Measurement

Proposed Measurements	Instruments	Range	Meteorological Effects
Aerosols Concentration	Lidar ABL ABA,ACF	H WS SS,ISS	Radiation Precipitation
Size	ABA ACF	SS IS	Radiation-Clouds
Elemental Composition	ACF	IS	Radiation-Clouds
Cloud-condensation nuclei (effective at <1% supersaturation)	ACF	IS	Clouds-precipitation
Ice nuclei (effective at -20°C water saturation)	ACF	IS	Clouds-precipitation
Aitken nuclei (effective at >100% supersaturation)	ABA ACF	SS,IS IS	Clouds-precipitation
Aerosol visible light scatter	ACF	IS	Clouds-precipitation
Insolation rates	Spectral pyrheliometer Pyranometer	IS IS	Solar Energy flux
Infrared radiation (downward)	IR radiometer	IS	Radiation balance
Infrared radiation (upward)	Airborne IR radiometer	WS	Radiation balance
Meteorological variables	Standard IS Instruments		
Temperature Humidity Wind Cloud cover			
Temperature inhomogeneities, inversion, stability of the atmosphere	Acoustic Sounder	HA	Pollution Trapping
Turbidity	Lidar* Integrating Nephelometer Volz turbidity meter	H IS	Visibility

Abbreviations

1. ACF - In-situ aerosol characterization facility (NOAA)
2. ABL - Airborne lidar (EPA-NERC-Las Vegas)
3. ABA - Airborne aerosol measurements (small aircraft, primarily spot sampling near Colstrip)
4. H - Over the hemisphere whose radius is the lidar range (10-20 km)
5. IS - In-situ ground sampling
6. SS - Spot sampling
7. WS - Wide area, less detailed sampling
8. HA - To height within the range of the acoustic sounder (up to 5000 ft.)

*Approximately, but over large volumes

released from the particles; and (3) spectrophotometric detection of atomic and molecular emissions with subsequent analysis in a multichannel analyzer.

Nuclepore membrane filters are exposed to the airstream of predetermined time intervals. The samples will be returned to NOAA's Wave Propagation Laboratory at Boulder, Colorado, for size distribution and elemental composition analysis of single particles by scanning electronmicroscopy and x-ray energy spectrometry.

Ground measurements will be verified by those from an instrumented light aircraft. The equipment consists of an isokinetic filter sampling probe used to collect samples for elemental and size distribution analyses; a Gardner fine particle counter; and an infrared radiometer for the in-situ measurement of the IR absorption coefficient. With this equipment the researchers will determine the vertical profile of Aitken nuclei concentrations, aerosol size distributions, and aerosol chemical composition. The radiometer data will be inverted into IR extinction coefficients, and the aerosol absorption index will be determined by a comparison of the measured and calculated extinction based on size distributions of the particles. These data permit conclusions regarding the effects of aerosols on radiometric measurements in the 8 to 12 μm atmospheric window.

The filter samples taken on the ground and in the air will be analyzed by a system using a scanning electron microscope (SEM) and an x-ray energy dispersive spectrometer (XES). This instrument classifies the low-volatile portion of the atmospheric aerosol by particle size, shape and elemental composition. The data from these instruments are correlated to the cloud physics parameters. This procedure will reveal the origins of atmospheric nuclei and their residence times and sinks.

The remote sensing lidar system will consist of multiple wavelength laser transmitters and receivers with polarization-sensitive detectors, a microwave radar, and a radiometer. Using these lidar techniques, the researchers intend to obtain data on the characteristics of atmospheric particulate matter over large areas of the atmosphere.

SCHEDULE

Generally, observations of aerosols will be confined to the growing season (April to October).

To establish baselines, observations will be made from 15 May to 15 June and 15 August to 15 September of 1975 while the power plant is not operating. Projections for future work are:

1976	May, August
1977	May, August
1978	May, August

Through the cooperation of NOAA and other laboratories joining with NERL, it will be possible to maintain a coordinated effort resulting in a more precise characterization of the Colstrip environment, both before and after the power plant goes into operation. The data collected in this phase will be available to the biologists so that biological effects observed on the ground can be correlated with recorded changes in air quality.

APPENDIX A

BIOMASS DYNAMICS AND PRIMARY PRODUCTION IN MIXED PRAIRIE GRASSLANDS IN SOUTHEASTERN MONTANA: BASELINE DATA FOR AIR POLLUTION STUDIES

by

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R. G. Woodmansee

INTRODUCTION

The extensive grasslands of southeastern Montana have been, until recently, the single most valuable resource in the region. Now with the crisis in energy supplies coal, another important resource in the region, is assuming increased importance, thus raising questions concerning the conflict between the two resource uses. This paper reports on primary producer biomass dynamics and productivity for four sites witin 20 km of an emission source, and for another site located at a distance of 60 km. The data for this report, from 1974, represent an estimate of baseline conditions for the sites from the year previous to the year of activation of the first of two and possibly four generating plants at Colstrip. Our project is part of a large total system study described by Lewis et al. (10). The research reported here is concerned with the characterization of the mixed-grass prairie in southeastern Montana. This characterization is the first phase of studies which are intended to assess the effects of atmospheric emissions from a large coal-burning electrical plant on the mixed-grass prairie.

Our long-term study plan is to determine the effect of the emissions on primary producer biomass dynamics and productivity by comparing pre-emission measurements (ecosystem characterization) with similar measurements taken for two or more years following activation of a nearby coal-fired generating plant complex. The four study sites have been established that, according to unpublished diffusion model predictions (Allen Lefohn and Robert Lewis, personal communication), will be exposed to a gradient of atmospheric pollution from the generating plants located at Colstrip, Montana. The sites are located at varying distances southeast of the generating plant. The direction of the prevailing winds are from the northwest.

Measurements of producer biomass dynamics and net production have not been previously reported for the mixed prairie in southeastern Montana. Several studies in this region have described structural characteristics (11, 19) and responses to various grazing treatments (5, 6). Net primary production and intraseasonal biomass dynamics have been reported for the mixed prairie in North Dakota (8) and South Dakota (3, 9).

Understanding the intraseasonal dynamics of primary producer and the net production of the grassland will be an important link in understanding the effects of power plant emissions on the mixed prairie ecosystem.

SITE DESCRIPTION

The study areas are located within the mixed prairie region of southeastern Montana. Four sites are near Colstrip in Rosebud County (Hay Coulee, Kluver West, and Kluver North, and Kluver East) while the remaining site is approximately 64 km southeast in the Fort Howes Division of Custer National Forest in Powder River County (Table 1). All five sites were fenced to exclude livestock prior to the 1974 grazing season. Taylor et al. (14) estimated the range condition of the sites as good to low good according to the method utilized by the Soil Conservation Service (13).

The mixed prairie has been characterized as a mixture of mid- and shortgrasses (17). Dominant grass species in the southeastern Montana region include western wheatgrass, (*Agropyron smithii*), needle-and-thread-grass (*Stipa comata*), green needlegrass (*Stipa viridula*), prairie June grass (*Koeleria cristata*), and Sandburg blue grass (*Poa secunda*). Other characteristic species include Japanese brome (*Bromus japonicus*), needleleaf sedge (*Carex eleocharis*), blue grama (*Bouteloua gracilis*), Hood's phlox (*Phlox hoodii*), common salsify (*Tragopogon dubius*), and fringed sagewort (*Artemisia frigida*).

The topography of the study region consists of steep rising buttes, and broad gently sloping valleys. The steeper buttes support *Pinus ponderosa-Juniperus scopulorum* communities whereas the hillsides and valleys are dominated by grasslands. The grassland soils were derived from parent material deposited as outwash from the surrounding buttes. Each site's geographical location, slope, aspect, elevation, soil texture and dominant species are presented in Table 1.

The Northern Plains climate is characterized as semiarid, continental and extremely variable (15). Long-term climatological records (T. Weaver, personal communication) from near Colstrip reveal a mean annual precipitation of 396 mm with approximately 50% falling during the spring growing months of April, May, and June. The mean monthly maximum temperature ranges from 32°C in July to 1°C in January with mean minimum temperatures approximately 17°C less. The average frostfree period is approximately 130 days beginning in mid-May (4).

METHODS

Above- and belowground plant biomass was sampled by the harvest method on six dates at the Colstrip sites (10 May, 15 June, 1 July, 24 July, 12 August, and 26 September) and two dates at the Ash Creek site (3 June and 10 July). On each date five circular 0.5-m^2 quadrats were clipped on each of two replicates at the Colstrip sites and on each of the eight replicates at the Ash Creek site. All aboveground biomass was separated by species and into the following categories: current live, recent dead (current year's production), old dead (previous year's production), and perennial live. Species or categories estimated to make up less than 1 g in any quadrat were not harvested. All harvested material was oven-dried at 60°C to a constant weight.

Litter biomass was collected with a vacuum cleaner after the standing biomass was removed. These samples were later rinsed with water, oven-dried, weighed, and ashed. All litter weights are expressed on an ash-free basis.

Belowground biomass was sampled from each harvested quadrat by means of three soil cores, 7.5 cm in diameter x 10 cm deep on each sample date. In addition to this on 27 July 10 cores 5 cm in diameter x 60 cm deep were taken on each site to assess the vertical distribution of belowground biomass. These soil cores were separted into 10-cm increments. Roots were removed from the soil cores by the method of Lauenroth and Whitman (7). The samples were then oven-dried, weighed, and ashed. Belowground biomass is reported on an ash-free basis.

RESULTS

Aboveground Biomass

Seasonal dynamics of total current live (CL), recent dead (RD), and old dead (OD) for the Colstrip sites are presented in Figure 1. Dynamics of the three categories was similar across sites. The peak in CL occurred on 15 June for all sites and all peaks were approximately 100 g/m^2. Differences among the sites in CL biomass were evident following the peak. Current live biomass declined steadily on the Hay Coulee and Kluver West sites until the last sample date. For Kluver East and Kluver North CL remained at a high level until mid-August.

Recent dead biomass increased throughout the season on all sites. The sites with a faster decline in CL also had a faster increase in RD. In all cases, RD peaked on the final date. Old dead which represents biomass carried over from previous growing seasons showed a peak early in the season and declined subsequently.

An overview of the dynamics of total biomass by categories indicates a high degree of similarity among sites. The seasonality of all sites is similar to other northern mixed prairie sites for which data are available (3, 8, 9).

Analysis of primary producer biomass dynamics by individual species should maximize the amount of information conveyed to the reader. However, the variability associated with estimates of individual biomass limits discussions to the most abundant species. For this reason we have placed emphasis on discussion of biomass dynamics by phenologically similar growth form groups (viz. cool season grass, warm season grasses, cool season forbs, warm season forbs, half-shrubs). Cool season species make the largest portion of their growth in spring and early summer, and warm season species make their maximum growth in summer and early fall. An additional reason for combining the data into groups is that cool season species have been found in general to have the C_3 Calvin-Benson pathway of CO_2 fixation while warm season species have the C_4 dicarboxylic acid pathway (18). The significance of this for the mixed prairie is that C_3 plants have a lower temperature optimum for photosynthesis than C_4 species (18) and hence their maximum growth is during the cooler portion of the growing season. This implies that this method of grouping approximates functional groups.

Cool season grasses are the most important group occurring on the sites. Figure 2 represents the dynamics of current season production (CL + RD) for cool season grasses and the three most important species comprising this group. Peaks in cool season grass production occurred during June and July in 1974 and ranged from 100 g/m^2 for the Kluver West site to 55 g/m^2 for Kluver North (Fig. 2a). The differences in cool season grass production among the sites are primarily attributable to differences in production of *Stipa comata* (Fig. 2b). Peak production for S. comata ranged from zero to more than 50 g/m^2. The sites separated into two groups on the basis of *Agropyron smithii* biomass (Fig. 2c). Hay Coulee and Kluver East had peaks in current season production of approximately 40 g/m^2 and remaining sites had peaks of approximately 20 g/m^2. The annual grass *Bromus japonicus* was most abundant on the Kluver West site (Fig. 2d).

Half-shrubs were the second most productive group occurring on the sites except for Kluver West where there were few half-shrubs. The dynamics of current season production was bimodal for all three sites (Fig. 3a). The early peak occurred in June and the second peak in August and September. *Artemisia frigida* contributed more than 80% of the current production in the half-shrub group on all three sites.

Warm season grasses (Fig. 3b) occurred on all four sites. Peak production ranged from 4 to 16 g/m^2. The peaks were not as distinct as in the previously mentioned groups largely because of the tendency of the major species *Bouteloua gracilis* to grow in patches. Standard errors for peak current season production estimates were typically greater than 25% of the mean for B. gracilis to grow in patches. Standard errors for peak current season production estimates were typically greater than 25% of the mean for B. gracilis compared to estimates of the same value for A. smithii which had standard errors of less than 25% of the mean. The sites with the greatest production of warm season grasses, Hay Coulee and Kluver North, had peaks in August.

Of the 24 species comprising the cool season forb group only one species, Tragopogon dubius, was found in amounts of 1 g or more on all sites. Peaks in cool season forb production occurred in June and July and ranged from 10 to 16 g/m^2 (Fig. 3c). The August peak measured on the Hay Coulee site was attributable to a dense patch of Phlox hoodii that occurred in one of the quadrats. We do not feel that the sample was a valid estimate of P. hoodii production for the entire site.

Warm season forbs was the least productive group with no one species occurring in amounts of 1 g or more on all sites. Peak production ranged from 0.14 to 3.5 g/m^2. No figure is presented for this group since measurable biomass was not encountered on all sites for several of the sample dates.

Since the Ash Creek site was sampled only twice during the 1974 season, no figures of these data are presented. Judging from the results from the other sites, we assume that the two samples were very close to the peak biomass of the majority of the species. Peak current season production of the various groups were similar to the Colstrip sites except that there were essentially no warm season grasses. Peak production for cool season grasses and cool season forbs was 73 and 21 g/m^2, respectively. Half-shrub production was 20 g/m^2 and warm season forbs contributed 2 g/m^2 to total production.

Litter Biomass

Estimates of litter standing crop ranged from less than 150 g/m^2 to more than 200 g/m^2 and exhibited few if any definite trends in seasonal dynamics (Fig. 4). It appears that a net decline may have occurred over the course of the growing season. Consistent differences in litter standing crop do not exist among the Colstrip sites. The Ash Creek site appears to have lower amounts of litter than the Colstrip sites, at least during early June (153 g/m^2) and early July (154 g/m^2).

Belowground Biomass

Since sampling was not initiated until 15 May, we gained an incomplete picture of the intraseasonal dynamics of root biomass in 1974. Although there were no dramatic changes in root biomass during the sampling period on the Colstrip sites, a net decline in root mass took place between May and September (Fig. 5). Since the sampling method used to determine root biomass does not partition the material into live and dead components, it is impossible to ascertain from these data the dynamics of each of these components (live and dead). Other studies (3, 9) have shown that there is often a decrease in root biomass very early in the season that is succeeded by an increase following more complete development of the photosynthetic tissue. We suspect that such a decrease occurred well before our first sampling date.

The vertical distribution of roots was examined on one date for each of the five study sites. Differences in the vertical distribution of root biomass did not exist among the Colstrip sites. However, the Ash Creek site had a higher proportion of the total root biomass in the 0-10 cm level than the Colstrip sites (Fig. 6). This may be the result of differences in botanical composition, soil characteristics, or grazing history. Differences between the areas do not exist when the 0-30 cm level proportions of total root biomass are compared for the Colstrip and Ash Creek (77% and 79%, respectively).

Net Primary Production

Many methods have been used to estimate net aerial production from harvest data (12) although it is difficult to determine a "best" method. We have selected two methods: The first involves summing the peak amounts of current production (live + recent dead) for each functional group, and the second method entails summing the peak production estimates of each species. The first method has the advantage of smaller standard errors associated with the estimates of current growth. The second method considers that the phenology of each species is distinct and that peak growth within the groups is not necessarily attained at the same time.

Net aerial primary production for the five sites estimated by the first method ranged from 106 to 123 g/m^2 (Fig. 7). Estimates by the second method were higher as expected and ranged from 117 to 149 g/m^2 (Table 2).

Dahlman and Kucera (2) have shown that minimal estimates of the portion of net primary production translocated belowground can be made by examining belowground biomass dynamics and considering significant increases within the season as belowground primary production. Only one site (Kluver West) exhibited a significant increase (about 120 g/m^2).

DISCUSSION

The suitability of the study sites to meet our objectives of assessing the effects of atmospheric emissions from a large coal-burning electrical power plant on the vegetation of the northern mixed prairie requires that they meet two general criteria. The first is that the sites are "typical" northern mixed prairie sites enabling us to generalize our results to a larger area; the second is that the sites are homogenous enough so that treatment effects can be separated from site differences.

From the point of view of vegetation structure our sites appear to be "typical" of many northern mixed prairie sites. Weaver and Clements (17) list the most widespread dominants of the mixed prairie as *Stipa comata*, *Sporobolus cryptandrus*, *Agropyron smithii*, *Koeleria cristata*, *Bouteloua gracilis*, and *Buchloe dactyloides*. *Agropyron smithii* is one of the dominants on all of our sites, sharing dominance with *Bouteloua gracilis* on the Hay Coulee site, *Stipa comata* on Kluver West, *Stipa comata* and *Artemisia frigida* on both the Kluver North and Kluver East sites, and *Koeleria cristata* on the Ash Creek site. Coupland (1) described the distribution of A. smithii as extending from southern Canada to Texas, and Weaver and Albertson (16) described *A. smithii* as one of four dominant grasses that occur throughout the extent of the mixed prairie.

Singh et al. (12) investigated the range of values obtained by 31 methods of calculating aboveground net primary production in grasslands from harvest data. They report 64 estimates of aboveground production for a northern mixed prairie site in North Dakota and 186 estimates for a similar site in South Dakota. The range of estimates for both grazed and ungrazed grasslands in North Dakota was 119 to 471 g/m^2. Estimates by the two techniques that we used in this paper were 351 g/m^2 by summing peak current production by species and 208 by summing peaks of functional groups for the ungrazed area and 208 by summing peaks of functional groups for the ungrazed area and 302 and 206 g/m^2 for the grazed area. In comparison our sites are less productive. The difference in production was mainly attributable to the greater productivity of *Stipa comata* on the North Dakota site.

Aerial net primary productivity estimates for the South Dakota site over 3 years of measurement ranged from 173 to 973 g/m^2 for the ungrazed treatment and 129 to 619 g/m^2 for the grazed (12). Estimates by summing species peaks ranged from 248 to 365 g/m^2 for the ungrazed grassland and 163 to 220 g/m^2 for the grazed. Summing peak production by groups yielded a range of 193 to 235 g/m^2 for the ungrazed and 139 to 249 g/m^2 for the grazed treamtent. Again the Montana sites were less productive than the South Dakota grassland, but the estimates overlap at the lower end of the range. Rainfall at the sites reported by Singh et al. (12) was above average during the years that harvest data were reported. Precipitation data from Colstrip, Montana, approximately 15 km from the sites indicate that April and May of 1974 were wetter than normal. but June, the month in which cool season grass peak production was measured, was 57 mm below average.

Analysis of variance of aerial net primary production by species groups (Table 3) indicates that there were no differences in average net primary production among the Colstrip sites in 1974, but that there was a significant ($P < 0.001$) site x functional group interaction. Evaluation of the site x group interaction revealed that the significant response was attributable to the data from the Kluver West site. The almost complete lack of half-shrubs on this site (Fig. 3) was compensated for by a 40% increase in the net production of cool season grasses (Fig. 2). Repeating the analysis without the Kluver West data (Table 4) resulted in a nonsignificant site x group interaction indicating that the contribution of species groups to net primary production was not different among the three remaining sites. On this basis we can conclude that three of our sites are similar enough to separate any effects of air pollution from site differences. These results do not mean that the Kluver West site will be of no use to our study because many of our future analyses will be concerned with the changes in individual sites as a function of time of exposure to power plant emissions. The dominant species on Kluver West site *Stipa comata* is well represented in other mixed prairie communities and the fact that we have two community types represented in our study may increase the generality of our results.

ACKNOWLEDGEMENTS

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Table 1. LOCATION, SLOPE AND ASPECT, ELEVATION, SOIL TYPE, AND DOMINANT PLANT SPECIES FOR FIVE MIXED PRAIRIE SITES IN SOUTHEASTERN MONTANA[1]

Sites	Location	Slope and Aspect	Elevation	Soils	Dominant Species[2]
Hay Coulee	12 km southeast of Colstrip	4% North	930 m	Clay loam	*Agropyron smithii* *Bromus japonicus* *Bouteloua gracilis* *Artemisia frigida* *Tragopogon dubius*
Kluver West	12 km east-southeast of Colstrip	6% North	920 m	Sandy loam	*Stipa comata* *Bromus japonicus* *Agropyron smithii*
Kluver North	15 km east-southeast of Colstrip	5% Northeast	900 m	Sandy loam	*Artemisia frigida* *Stipa comata* *Agropyron smithii* *Bromus japonicus* *Tragopogon dubius* *Bouteloua gracilis*
Kluver East	19 km east-southeast of Colstrip	3 1/2% Northeast	900 m	Clay loam	*Agropyron smithii* *Artemisia frigida* *Bromus japonicus* *Stipa comata*
Ash Creek	64 km southeast of Ashland	4-5% Northeast	1170 m	Silt loam	*Agropyron smithii* *Koeleria cristata* *Calamagrostis montanensis* *Bromus japonicus* *Artemisia cana*

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[1] Site description after Taylor et al. (14).

[2] Based on harvest data in 1974

Table 2. PEAK CURRENT SEASON PRODUCTION (G/M^2), STANDARD ERROR OF ESTIMATE, AND THE DATE (DAY/MO), WHEN THE PEAK OCCURRED, BY SPECIES, FOR FIVE MIXED PRAIRIE SITES IN SOUTHEASTERN MONTANA IN 1974.

Species	Hay Coulee			Kluver West			Kluver North			Kluver East			Ash Creek		
	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date
COOL SEASON GRASSES															
Agropyron cristatum										12.00	3.00	2/7			
Agropyron smithii	43.00	3.00	11/6	17.00	5.00	30/6	24.00	6.00	25/7	39.00	5.00	18/6	23.00	4.80	10/7
Bromus japonicus	23.00	4.00	29/6	31.00	3.00	20/6	19.00	5.00	12/6	9.00	2.00	2/7	14.00	6.50	10/7
Calamagrostis montanensis													9.00	2.30	10/7
Carex eleocharis													0.40	0.32	10/7
Carex filifolia				5.00	1.00	15/5	4.00	3.00	1/7						
Carex pennsylvanica													0.43	1.20	3/6
Festuca octoflora	0.16	0.06	29/6	0.18	0.02	24/7	0.04	0.03	12/6	0.02	0.02	2/7	0.21	0.24	3/6
Koeleria cristata	5.00	3.00	29/6	0.53	0.45	24/7	1.00	0.67	1/7	0.04	0.03	12/5	25.00	2.80	3/6
Poa secunda	2.00	0.50	11/5	0.77	0.33	15/5	1.00	0.39	12/5	0.84	0.41	12/5	9.00	2.00	3/6
Stipa comata	0.14	0.14	11/5	57.00	5.00	30/6	32.00	8.00	28/9	7.00	3.00	2/7	0.58	0.68	10/7
WARM SEASON GRASSES															
Aristida longiseta				0.04	0.04	22/8	3.00	2.00	12/8						
Bouteloua gracilis	16.00	4.00	16/8	4.00	2.00	20/6	11.00	4.00	12/8	6.00	3.00	2/7			
Schedonnardus paniculatus	0.02	0.02	29/6							0.48	0.46	12/5			
Sporobolus cryptandrus	0.02	0.02	26/9												
WARM SEASON FORBS															
Antennaria neglecta	0.06	0.02	11/5	0.10	0.03	15/5	0.02	0.02	12/6				0.30	0.47	3/6
Arnica fulgens													0.12	0.46	3/6
Circium undulatum										0.02	0.02	2/7			
Conyza canadensis							0.06	0.04	12/8				0.32	0.25	10/7
Erigeron spp.													0.71	1.00	10/7
Gaura coccinea	0.02	0.02	11/5	0.02	0.02	30/6	0.08	0.05	25/7	0.04	0.04	23/7	0.31	0.29	10/7

Table 2. Continued

Species	Hay Coulee			Kluver West			Kluver North			Kluver East			Ash Creek		
	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date
Grindelia squarrosa							0.47	0.47	1/7						
Lygodesmia juncea				1.00	0.82	30/6									
Orthocarpus lutea													0.72	0.49	10/7
Polygala alba	0.08	0.06	16/8							0.04	0.04	26/9			
Psoralea argophylla				2.00	1.00	30/6							2.00	1.00	10/7
Psoralea tenuiflora				0.08	0.05	24/7	0.55	0.53	12/6	0.04	0.04	23/7	2.00	2.00	10/7
Ratibida columnifera													0.008	0.008	3/6
Senecio spp.							0.27	0.27	1/7						
Solidago rigida													0.13	5.00	10/7
COOL SEASON FORBS															
Achillea millefolium	0.02	0.02	11/5										15.00	5.00	10/7
Androsace occidentalis	0.06	0.02	11/6	0.06	0.02	15/5	0.04	0.02	12/6				0.08	0.02	10/7
Astragalus spp.				0.04	0.04	24/7	0.15	0.13	12/5				0.06	0.15	10/7
Cymopterus acaulis	0.02	0.02	11/5				0.02	0.02	12/5				0.001	0.005	10/7
Descurainia spp.				0.02	0.02	28/9									
Draba reptans				0.12	0.03	15/5									
Erysimum asperum				1.00	1.00	30/6	1.00	0.91	1/7	0.63	0.58	2/7			
Hedeoma hispida	0.50	0.26	29/6	0.28	0.06	30/6	0.20	0.07	1/7	0.10	0.03	23/7	0.12	0.03	10/7
Lappula redowskii													0.07	0.29	3/6
Lepidium densiflorum	0.12	0.03	11/6	0.08	0.03	20/6	0.16	0.06	1/7	0.02	0.02	2/7			
Leucocrinum montanum				0.77	0.35	15/5	0.47	0.16	12/5	0.10	0.10	18/6	0.07	0.07	3/6
Lithospermum incisum													0.22	0.24	3/6
Linum rigidum	0.42	0.29	16/8												
Lomatium orientale	0.06	0.02	11/5	0.04	0.02	15/5	0.02	0.02	12/5				0.02	0.02	3/6
Penstemon spp.							0.02	0.02	28/9						
Plantago patagonia	0.36	0.03	29/6	3.00	1.00	30/6	0.28	0.06	1/7	0.16	0.06	2/7	0.62	0.50	3/6
Phlox hoodii	6.00	5.00	16/8	2.00	2.00	15/5				3.00	3.00	13/8	3.00	3.00	3/6
Selaginella densa													0.003	0.01	10/7
Sphaeralcea coccinea	0.04	0.02	11/5	1.04	0.93	20/6	1.00	1.00	25/7				0.46	0.26	3/6

Table 2. Continued

Species	Hay Coulee			Kluver West			Kluver North			Kluver East			Ash Creek		
	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date
Taraxicum officinale	3.00	0.85	11/5	0.41	0.28	20/6	0.17	0.13	12/5	0.24	0.07	2/7	3.00	1.00	3/6
Tragapogon dubius	9.00	2.00	29/6	5.00	0.59	20/6	12.00	1.00	1/7	6.00	1.00	2/7	2.00	1.00	10/7
Vicia americana													0.002	0.01	10/7
Zygadenus elegans													0.07	0.09	3/6
Misc.	0.10	0.03	11/5	0.17	0.17	30/6	0.02	0.02	12/5				0.42	0.47	3/6
HALF-SHRUBS															
Artemisia cana	0.04	0.04	26/7										0.25	0.41	3/6
Artemisia dracunculoides							0.02	0.02	1/7	0.04	0.04	23/7	0.01	0.05	10/7
Artemisia frigida	11.00	4.00	29/6	0.27	0.23	30/6	37.00	5.00	12/8	29.00	6.00	18/6	12.00	4.00	10/7
Artemisia ludoviciana													2.00	2.00	10/7
Artemisia tridentata	0.08	0.06	16/8												
Eurotia lanata	2.00	2.00	11/5												
Gutierrezia sarothrae	0.45	0.45	26/9										5.00	3.00	10/7
Rosa arkansana													0.001	0.005	10/7
OTHERS															
Parmelia chlorochroa				0.02	0.02	15/5	0.02	0.02	12/6						
Mammilaria spp.				0.08	0.06	24/7	0.04	0.04	25/7						
Opuntia polyacantha	0.04	0.02	29/6				0.08	0.06	25/7	0.57	0.57	18/6			
Opuntia fragilis	0.04	0.04	26/7	0.04	0.03	30/6	0.08	0.06	25/7	0.04	0.04	23/7			
Echinocereus viridiflorus				0.41	0.29	20/6									
TOTAL NET PRODUCTION		123			134			149			114			133	

Table 3. Analysis of variance for the response of aerial net primary production to the four Colstrip sites and five primary producer groups.

Source	d.f.	Sum of Squares	Mean Square	F	P
Sites	3	92.26	31.09	0.46	0.713
Groups	4	22749.10	5687.28	84.52	<0.0001
Site x Group	12	7649.99	637.50	9.47	<0.0001
Error	20	1345.83	67.29		

Table 4. Analysis of variance for the response of aerial net primary production to the Kluver North, Kluver East and Hay Coulee sites and five primary producer groups.

Source	d.f.	Sum of Squares	Mean Square	F	P
Sites	2	74.81	37.40	0.43	0.658
Groups	4	13864.85	3466.21	40.15	<0.0001
Site x Group	8	776.16	97.02	1.12	0.404
Error	15	1295.08	86.34		

FIGURE TITLES

Fig. 1 Seasonal dynamics of current live, recent dead, and old dead biomass for the four Colstrip sites in 1974: (a) Hay Coulee (b) Kluver North, (c) Kluver East, and (d) Kluver West.

Fig. 2 Seasonal dynamics of current production (current live + recent dead) of (a) cool season grasses, (b) *Stipa comata*, (c) *Agropyron smithii*, and (d) *Bromus japonicus* for the four Colstrip sites in 1974.

Fig. 3 Seasonal dynamics of current production (current live + recent dead) of (a) half-shrubs, (b) warm season grasses, and (c) cool season forbs for the four Colstrip sites in 1974.

Fig. 4 Seasonal dynamics of litter biomass for the four Colstrip sites in 1974.

Fig. 5 Seasonal dynamics of root biomass for the four Colstrip sites in 1974.

Fig. 6 Comparison of the vertical distribution of root biomass between the mean of the four Colstrip sites and the Ash Creek site.

Fig. 7 Functional group composition of total net aerial production and standard errors for the five mixed prairie sites in southeastern Montana in 1974.

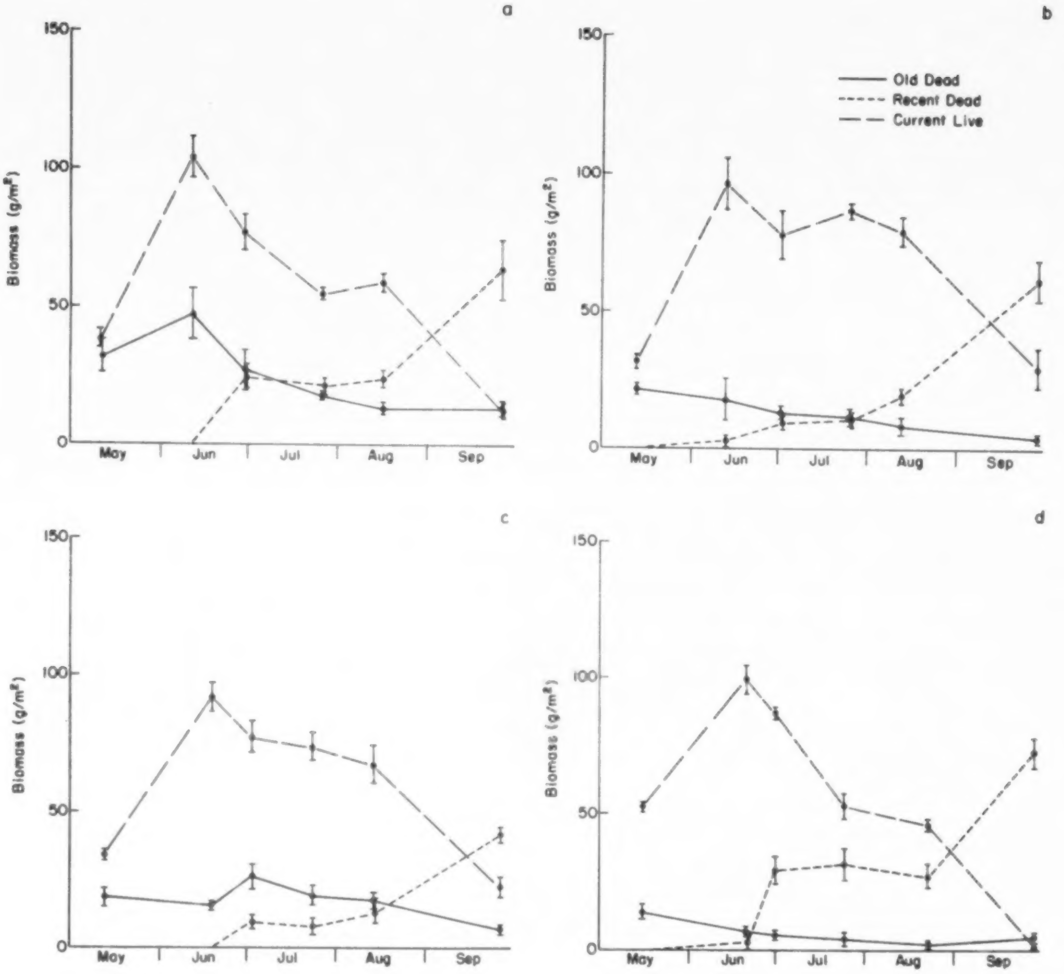

Fig. 1 Seasonal dynamics of current live, recent dead, and old dead biomass for the four Colstrip sites in 1974: (a) Hay Coulee (b) Kluver North, (c) Kluver East, and (d) Kluver West.

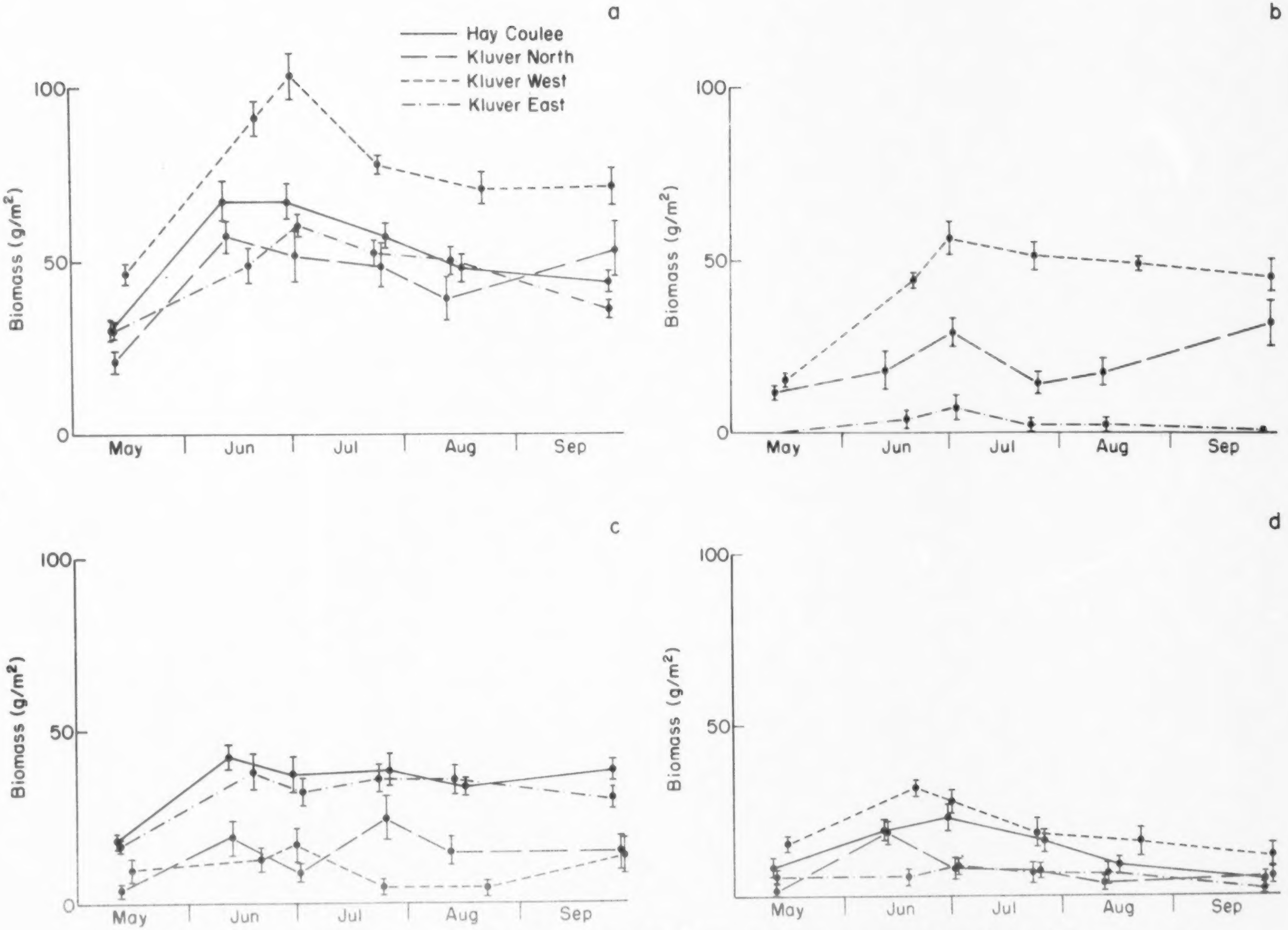

Fig. 2 Seasonal dynamics of current production (current live + recent dead) of (a) cool season grasses, (b) *Stipa comata*, (c) *Agropyron smithii*, and (d) *Bromus japonicus* for the four Colstrip sites in 1974.

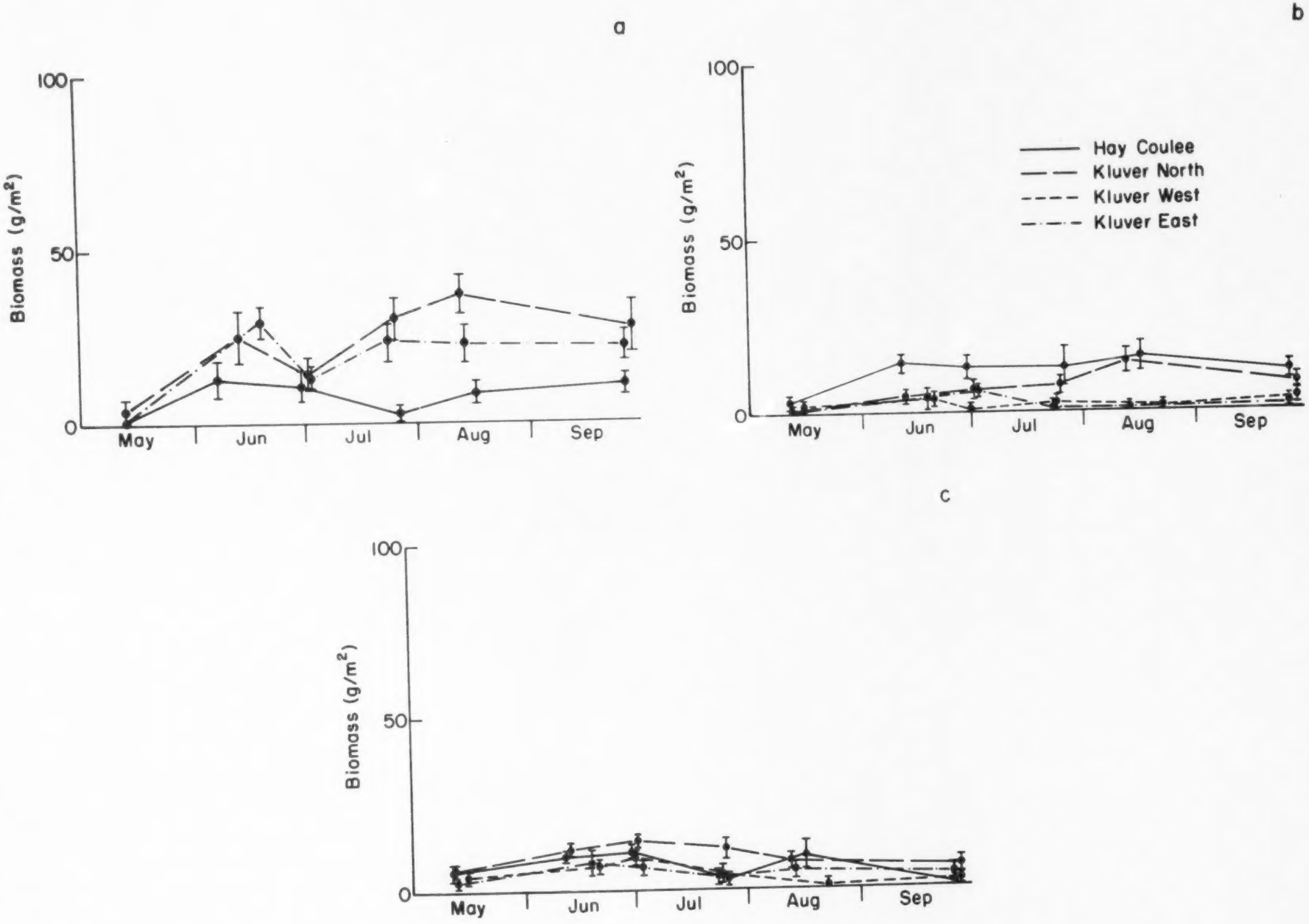

Fig. 3 Seasonal dynamics of current production (current live + recent dead) of (a) half-shrubs, (b) warm season grasses, and (c) cool season forbs for the four Colstrip sites in 1974.

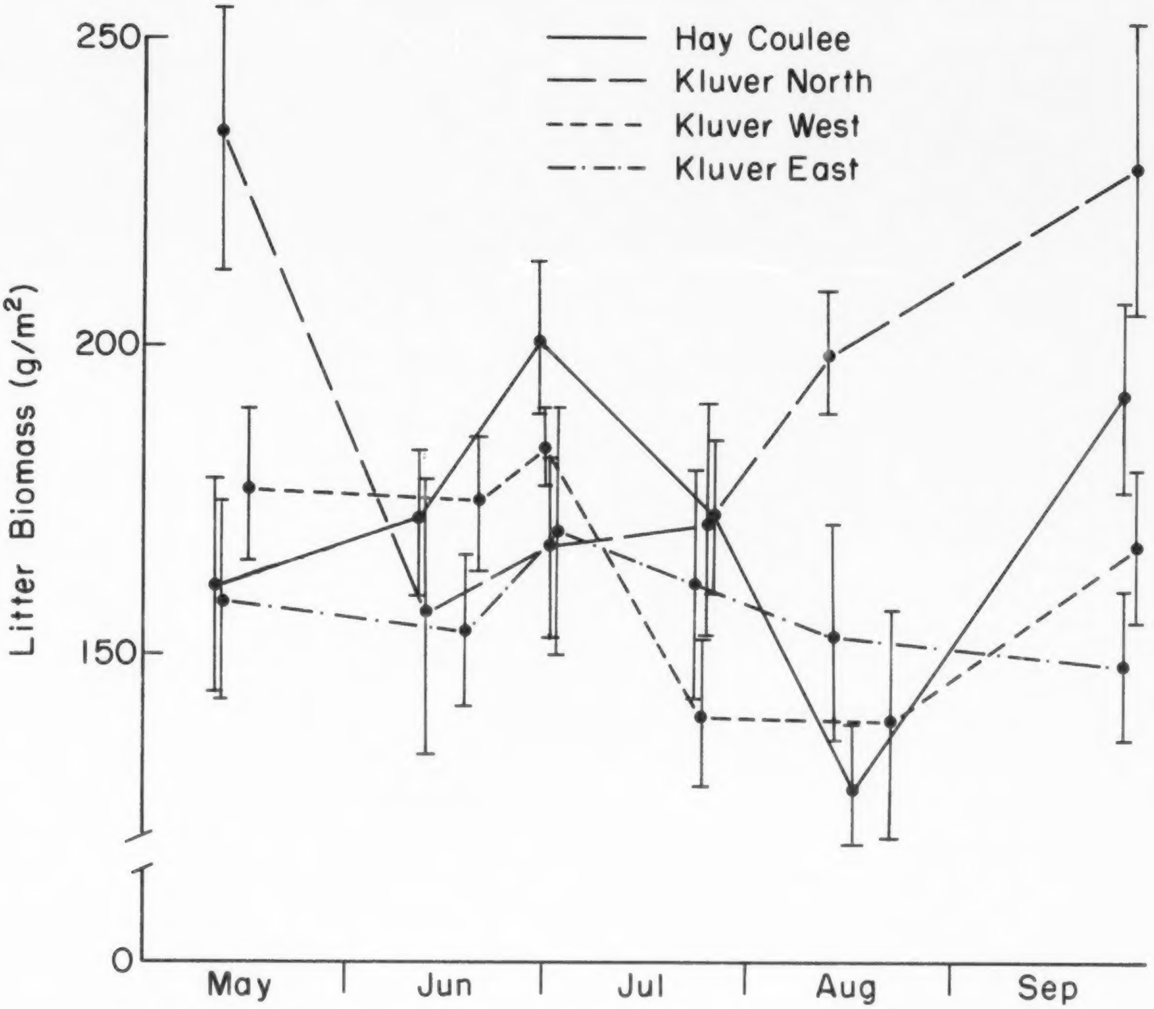

Fig. 4 Seasonal dynamics of litter biomass for the four Colstrip sites in 1974.

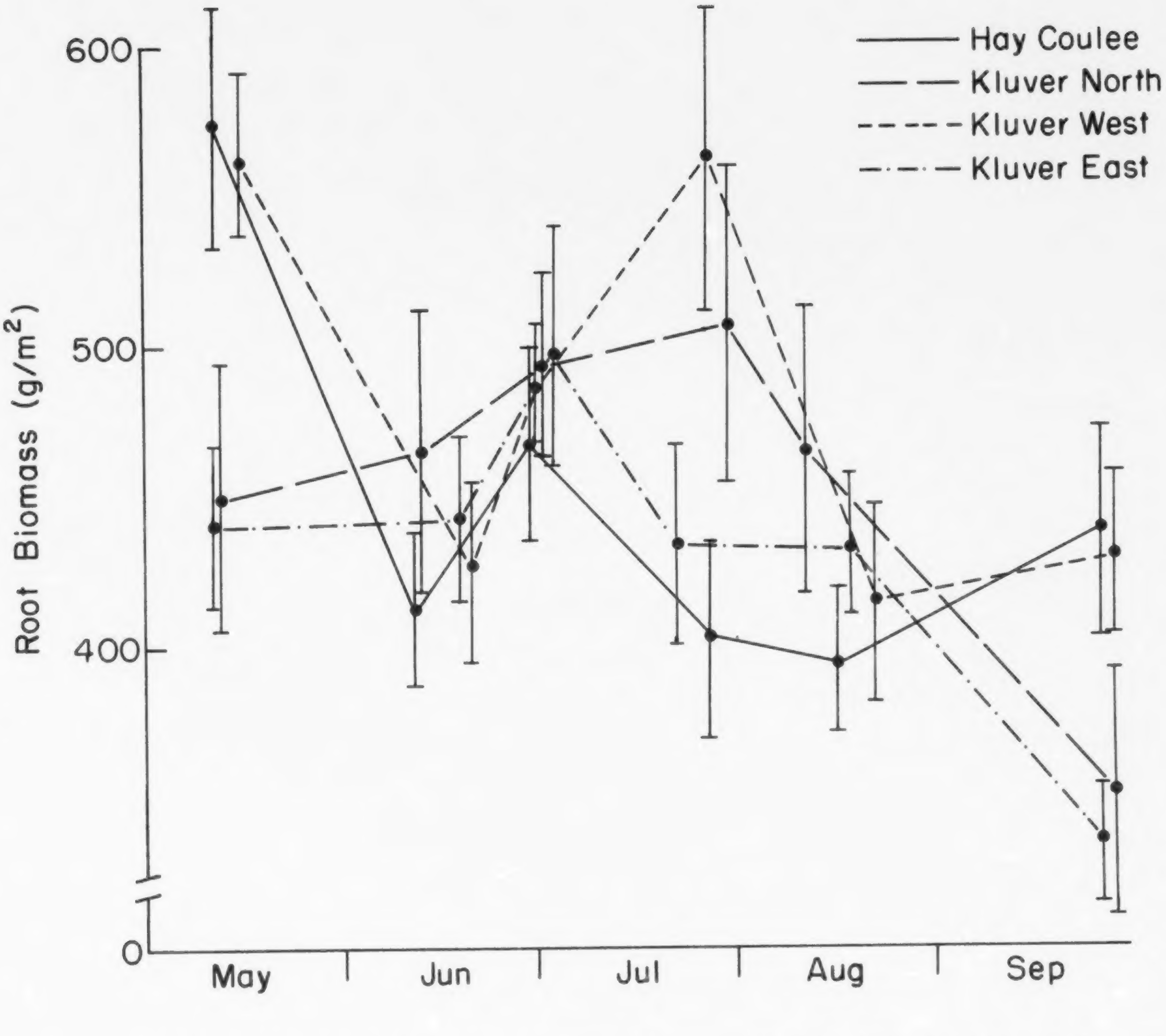

Fig. 5 Seasonal dynamics of root biomass for the four Colstrip sites in 1974.

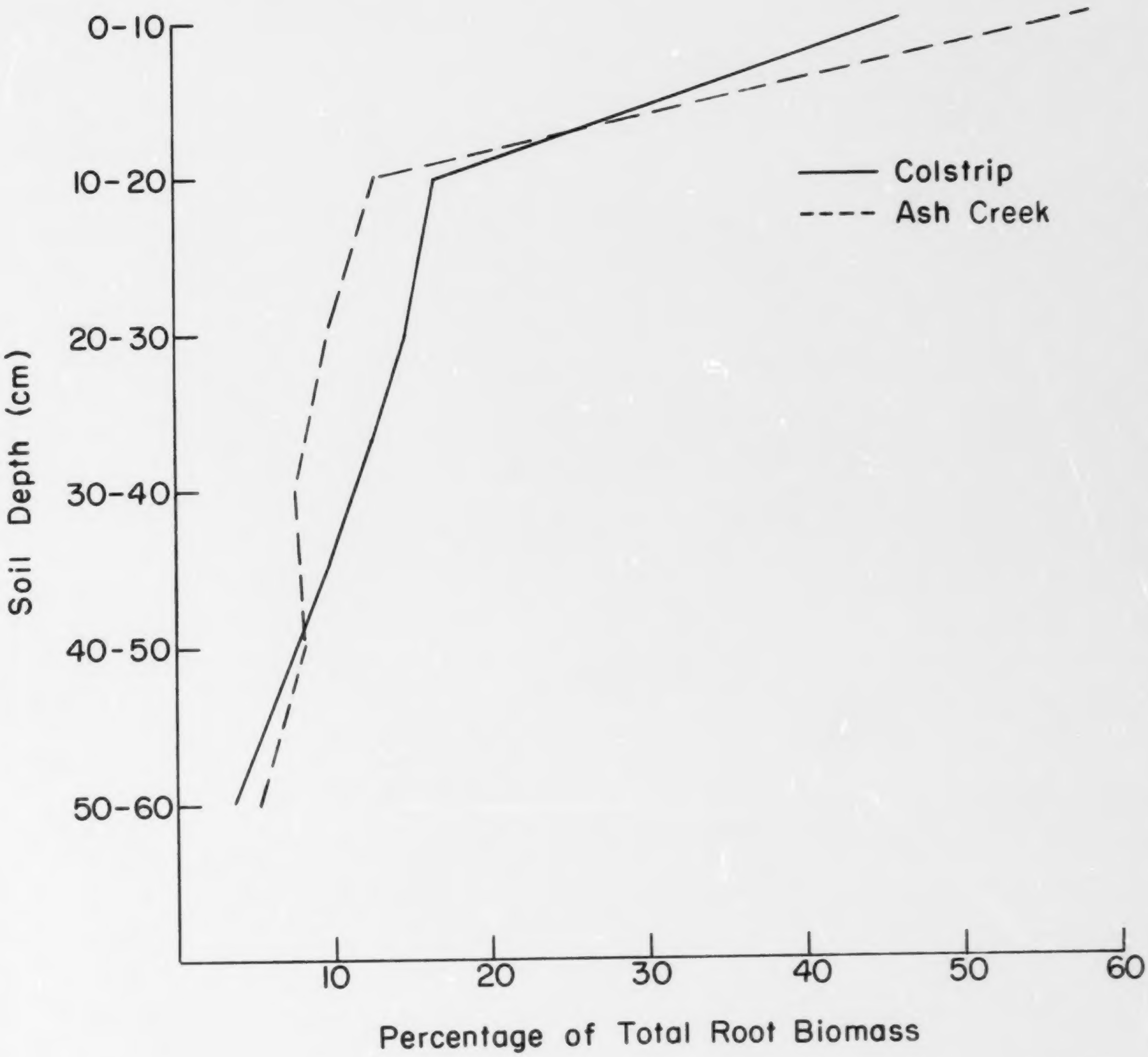

Fig. 6 Comparison of the vertical distribution of root biomass between the mean of the four Colstrip sites and the Ash Creek site.

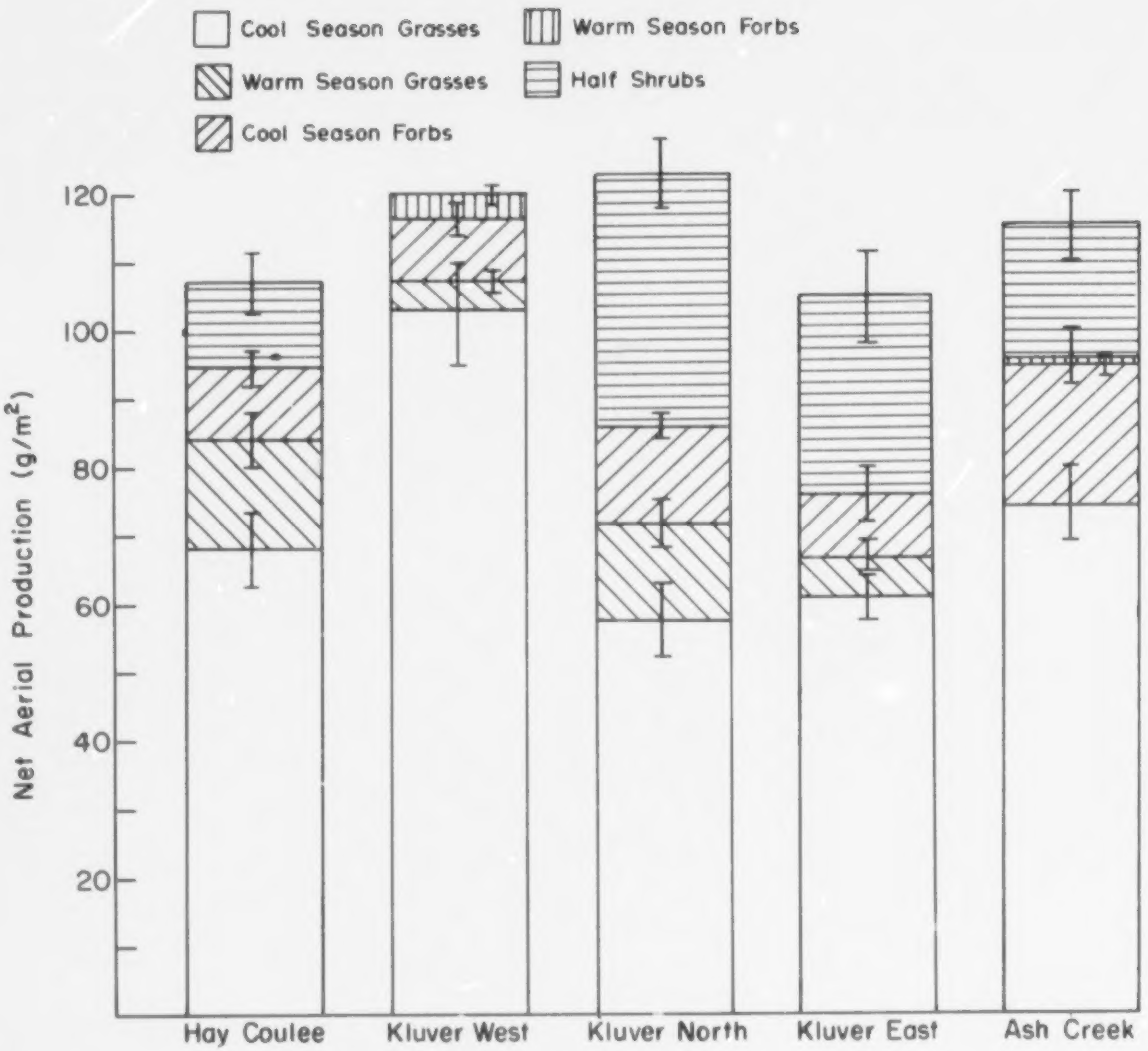

Fig. 7 Functional group composition of total net aerial production and standard errors for the five mixed prairie sites in southeastern Montana in 1974.

APPENDIX B - PART I
COLSTRIP SAMPLES - VEGETATION - FLUORIDE
FALL, 1974

F#	Site	Species Scientific Name	Species Common Name	Ppm F^- (by year)			
				71	72	73	74
2001-A (1495)	SE #1	Pinus ponderosa	Ponderosa Pine	6.3	3.0	3.5	2.6
2002-A (1496)	"	Juniperous scopulorum	Rocky Mtn. Juniper				2.2
2003-A (1497)	"	Andropogon scoparius	Little Bluestem				2.0
2004-A (1498)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.7
2005-A (1499)	"	Calamovilfa longifolia	Sandgrass				2.0
2006-A (1490)	"	Pinus ponderosa	Ponderosa Pine	2.5	2.6	2.0	1.7
2007-A (1491)	"	Juniperous scopolorum	Rocky Mtn. Juniper				2.0
2008-A (1492)	"	Andropogon scoparius	Little Bluestem				1.6
2009-A	"						
2010-A (1494)	"	Calamovilfa longifolia	Sandgrass				2.0
2011-A (1485)	"	Pinus ponderosa	Ponderosa Pine	1.2	2.0	1.7	2.7
2012-A (1486)	"	Juniperous scopulorum	Rocky Mtn. Juniper				2.6
2013-A (1487)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.1
2014-A (1488)	"	Andropogon scoparius	Little Bluestem				2.0
2015-A	"	Calamovilfa longifolia	Sandgrass				1.7
2016-A (1480)	"	Pinus ponderosa	Ponderosa Pine	1.7	4.1	3.1	2.4
2017-A (1481)	"	Juniperous scopulorum	Rocky Mtn. Juniper				2.8
2018-A (1482)	"	Calamovilfa longifolia	Sandgrass				1.7
2019-A (1483)	"	Andropogon scoparius	Little Bluestem				2.2
2020-A (1484)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.7
2021-A (1475)	"	Pinus ponderosa	Ponderosa Pine	1.9	3.3	2.4	1.5
2022-A (1476)	"	Juniperous scopulorum	Rocky Mtn. Juniper				2.4

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F^- (by year)			
				71	72	73	74
2023-A (1477)	SE #1	Artemisia cana	Silver Sage				0.8
2024-A (1478)	"	Andropogon scoparius	Little Bluestem				2.9
2025-A (1479)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.1
2076-A (1200)	W #4	Pinus ponderosa	Ponderosa Pine	4.1	2.8	3.3	2.4
2077-A (1201)	"	Rhus trilobata	Skunkbrush				1.3
2078-A (1202)	"	Artemisia cana	Silver Sage				3.5
2079-A (1203)	"	Andropogon scoparius	Little Bluestem				2.2
2080-A (1204)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.2
2081-A (1205)	"	Pinus ponderosa	Ponderosa Pine	4.3	2.9	1.9	2.4
2082-A (1206)	"	Artemisia cana	Silver Sage				2.5
2083-A (1207)	"	Rhus trilobata	Skunkbrush				2.0
2084-A (1208)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.9
2085-A (1209)	"	Andropogon scoparius	Little Bluestem				1.4
2086-A 1210)	"	Pinus ponderosa	Ponderosa Pine	3.5	1.4	2.9	1.1
2087-A (1211)	"	Artemesia cana	Silver Sage				3.5
2088-A (1212)	"	Rhus trilobata	Skunkbrush				1.7
2089-A (1213)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.0
2090-A (1214)	"	Adropogon scoparius	Little Bluestem				0.8
2091-A (1215)	"	Pinus ponderosa	Ponderosa Pine	1.3	2.4	1.9	1.3
2092-A (1216)		Rhus trilobata	Skunkbrush				2.6
2093-A (1217)	"	Artemisia cana	Silver Sage				2.4
2094-A (1218)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.2
2095-A (1219)	"	Andropogon scoparius	Little Bluestem				3.1
2096-A (1220)	"	Pinus ponderosa	Ponderosa Pine	1.9	3.3	2.8	2.3

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F^- (by year) 71	72	73	74
2097-A	W #4	Rhus trilobata	Skunkbrush				1.7
(1221) 2098-A	"	Artemisia cana	Silver Sage				3.3
(1222) 2099-A	"	Agropyron spicatum	Bluebunch Wheatgrass				1.0
(1223) 2100-A	"	Andropogon scoparius	Little Bluestem				1.7
(1224) 2101-A	W #3	Pinus ponderosa	Ponderosa Pine	3.7	3.0	2.3	2.7
(1750) 2102-A	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.0
(1751) 2103-A	"	Artemisia cana	Silver Sage				3.9
(1752) 2104-A	"	Agropyron spicatum	Bluebunch Wheatgrass				1.5
2105-A	"	Yucca glauca	Yucca				2.0
2106-A	"	Pinus ponderosa	Ponderosa Pine	3.3	2.8	3.0	1.8
(1755) 2107-A	"	Juniperus scopulorum	Rocky Mtn. Juniper				3.0
(1756) 2108-A	"	Artemisia cana	Silver Sage				2.5
2109-A	"	Agropyron spicatum	Bluebunch Wheatgrass				1.3
2110-A	"	Aristida longiseta	Red Three Awn				1.2
2111-A	"	Pinus ponderosa	Ponderosa Pine	2.0	1.0	1.8	1.1
(1760) 2112-A	"	Juniperous scopulorum	Rocky Mtn. Juniper				1.3
(1761) 2113-A	"	Artemisia cana	Silver Sage				0.8
(1762) 2114-A	"	Agropyron spicatum	Bluebunch Wheatgrass				1.7
(1763) 2115-A	"	Andropogon scoparius	Little Bluestem				1.1
2116-A	"	Pinus ponderosa	Ponderosa Pine	1.5	1.1	1.3	1.0
(1765) 2117-A	"	Juniperous scopulorum	Rocky Mtn. Juniper				1.7
(1766) 2118-A	"	Yucca glauca	Yucca				0.8
(1767) 2119-A	"	Agropogon spicatum	Bluebunch Wheatgrass				1.6
(1768) 2120-A	"	Andropogon scoparius	Little Bluestem				1.0

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F$^-$ (by year)			
				71	72	73	74
2121-A (1770)	W #3	Pinus ponderosa	Ponderosa Pine	1.3	0.7	1.3	1.2
2122-A (1771)	"	Juniperous scopulorum	Rocky Mtn. Juniper				2.0
2123-A (1772)	"	Yucca glauca	Yucca				1.1
2124-A (1773)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.2
2125-A (1774)	"	" "	" "				1.2
2126-A (1350)	NW #4	Pinus ponderosa	Ponderosa Pine	3.6	2.8	2.4	2.2
2127-A (1351)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.8
2128-A (1352)	"	Rhus trilobata	Skunkbrush				1.7
2129-A (1353)	"	Agropyron spicatum	Bluebunch Wheatgrass				5.9
2130-A (1354)	"	Andropogon scoparius	Little Bluestem				2.2
2131-A (1355)	"	Pinus ponderosa	Ponderosa Pine	3.8	4.0	2.5	1.7
2132-A (1356)	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.3
2133-A (1357)	"	Rhus trilobata	Skunkbrush				1.5
2134-A (1358)	"	Agropyron spicatum	Bluebunch Wheatgrass				0.9
2135-A (1359)	"	Andropogon scoparius	Little Bluestem				2.1
2136-A (1360)	"	Pinus ponderosa	Ponderosa Pine	1.4	1.1	2.1	1.2
2137-A (1361)	"	Rhus trilobata	Skunkbrush				1.4
2138-A (1362)	"	Artemisia cana	Silver Sage				1.1
2139-A (1363)	"	Agropyron spicatum	Bluebunch Wheatgrass				5.1
2140-A (1364)	"	Andropogon scoparius	Little Bluestem				4.3
2141-A (1365)	"	Pinus ponderosa	Ponderosa Pine	2.9	2.2	1.3	0.6
2142-A (1366)	"	Rhus trilobata	Skunkbrush				1.7
2143-A (1367)	"	Juniperus scopulorum	Rocky Mtn. Juniper				--
2144-A (1368)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.5

COLSTRIP SAMPLES (Continued)

		Species	Species	Ppm F^- (by year)			
F#	Site	Scientific Name	Common Name	71	72	73	74
2145-A (1369)	NW #4	Andropogon scoparius	Little Bluestem				1.5
2146-A (1370)	"	Pinus ponderosa	Ponderosa Pine	1.0	1.7	1.1	0.8
2147-A (1371)	"	Rhus trilobata	Skunkbrush				1.5
2148-A (1372)	"	Artemisia cana	Silver Sage				1.6
2149-A (1373)	"	Andropogon scoparius	Little Bluestem				1.1
2150-A (1374)	"	Calamovilfa longifolia	Sandgrass				0.7
2151-A (1775)	NW #3	Pinus ponderosa	Ponderosa Pine	3.6	3.2	3.2	3.3
2152-A (1776)	"	Juniperous scopulorum	Rocky Mtn. Juniper				2.3
2153-A (1777)	"	Artemisia tridentata	Big Sage				5.0
2154-A (1778)	"	Agropyron spicatum	Blue Bunch Wheatgrass				1.2
2155-A (1779)	"						
2156-A (1780)	"	Pinus ponderosa	Ponderosa Pine	3.5	2.0	2.6	1.1
2157-A (1781)	"	Artemisia tridentata	Big Sage				5.3
2158-A (1782)	"	Artemisia cana	Silver Sage				2.5
2159-A (1783)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.1
2160-A (1784)	"	Aristida longiseta	Red Three Awn				1.2
2161-A (1785)	"	Pinus ponderosa	Ponderosa Pine	2.3	1.5	1.9	0.9
2162-A (1786)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.2
2163-A (1787)	"	Artemisia cana	Silver Sage				1.2
2164-A (1788)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.4
2165-A	"	Andropogon scoparius	Little Bluestem				1.9
2166-A (1790)	"	Pinus ponderosa	Ponderosa Pine	1.7	2.3	1.6	0.9
2167-A (1791)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.9
2168-A (1792)	"	Artemisia cana	Silver Sage				2.3

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F^- (by year) 71	72	73	74
2169-A (1793)	NW #3	Agropyron spicatum	Bluebunch Wheatgrass				1.4
2170-A (1794)	"	Aristida longiseta	Red Three Awn				1.3
2171-A (1795)	"	Pinus ponderosa	Ponderosa Pine	1.9	1.2	1.8	1.2
2172-A (1796)	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.8
2173-A (1797)	"	Artemisia cana	Silver Sage				1.9
2174-A (1798)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.1
2175-A (1799)	"	Calamovilfa longifolia	Sandgrass				1.0
2176-A (1575)	NE #3	Pinus ponderosa	Ponderosa Pine	2.6	2.2	1.7	1.8
2177-A 1576)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.5
2178-A (1577)	"	Artemisia cana	Silver Sage				2.0
2179-A (1578)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.3
2180-A (1579)	"	Andropogon scoparius	Little Bluestem				2.2
2181-A (1580)	"	Pinus ponderosa	Ponderosa Pine	1.7	1.4	1.9	1.6
2182-A (1581)	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.8
2183-A (1582)	"	Artemisia cana	Silver Sage				3.7
2184-A (1583)	"	Agropyron spicatum	Bluebunch Wheatgrass				4.9
2185-A (1584)	"	Adropogon scoparius	Little Bluestem				3.9
2186-A (1585)	"	Pinus ponderosa	Ponderosa Pine	2.4	2.5	1.9	1.3
2187-A (1586)	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.9
2188-A (1587)	"	Chrysothamnus nauseosus	Rubber Rabbitbrush				1.8
2189-A (1588)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.6
2190-A (1589)	"	Andropogon scoparius	Little Bluestem				7.2
2191-A (1590)	"	Pinus ponderosa	Ponderosa Pine	3.0	2.5	2.5	1.6
2192-A (1591)	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.9

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F$^-$ (by year) 71	72	73	74
2193-A (1592)	NE #3	Artemisia tridentata	Big Sage				3.4
2194-A (1593)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.1
2195-A (1594)	"	Andropogon scoparius	Little Bluestem				3.3
2196-A (1595)	"	Pinus ponderosa	Ponderosa Pine	2.0	2.2	2.5	2.6
2197-A (1596)	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.9
2198-A (1597)	"	Artemisia tridentata	Big Sage				3.9
2199-A (1598)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.2
2200-A (1599)	"	Andropogon scoparius	Little Bluestem				3.9
2201-A (1050)	SE #3	Pinus ponderosa	Ponderosa Pine	3.3	1.1	2.9	2.2
2202-A	"	Yucca glauca	Yucca				1.5
2203-A	"	Andropogon scoparius	Little Bluestem				1.3
2204-A (1053)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.5
2205-A (1054)	"	Stipa comata	Needle and Thread				2.4
2206-A (1055)	"	Pinus ponderosa	Ponderosa Pine	2.6	3.6	1.7	1.9
2207-A	"	Artemisia cana	Silver Sage				3.2
2208-A (1057)	"	Chrysothamnus viscidiflorus	Green Rabbitbrush				2.5
2209-A (1058)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.5
2210-A (1059)	"	Stipa comata	Needle and Thread				2.2
2211-A (1060)	"	Pinus ponderosa	Ponderosa Pine	2.8	3.6	3.7	1.9
2212-A	"	Andropogon scoparius	Little Bluestem				0.9
2213-A (1062)	"	Chrysothamnus viscidiflorus	Green Rabbitbrush				2.9
2214-A (1063)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.0
2215-A (1064)	"	Stipa comata	Needle and Thread				1.3

COLSTRIP SAMPLES (Continued)

		Species	Species	Ppm F^- (by year)			
F#	Site	Scientific Name	Common Name	71	72	73	74
2216-A (1065)	SE #3	Pinus ponderosa	Ponderosa Pine	2.3	2.7	1.2	1.3
2217-A	"	Andropogon scoparius	Little Bluestem				1.1
2218-A (1067)	"	Chrysothamnus viscidiflorus	Green Rabbitbrush				1.7
2219-A (1068)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.3
2220-A (1069)	"	Stipa comata	Needle and Thread				1.8
2221-A (1070)	"	Pinus ponderosa	Ponderosa Pine	1.8	1.4	1.8	1.9
2222-A	"	Chrysothamnus viscidiflorus	Green Rabbitbrush				3.3
2223-A	"	Andropogon scoparius	Little Bluestem				1.1
2224-A (1073)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.1
2225-A (1074)	"	Stipa comata	Needle and Thread				1.3
2226-A (1275)	E #3	Pinus ponderosa	Ponderosa Pine	3.9	2.5	3.0	2.0
2227-A (1276)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.7
2228-A	"	Stipa comata	Needle and Thread				3.2
2229-A (1278)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.9
2230-A (1279)	"	Andropogon scoparius	Little Bluestem				2.6
2231-A (1280)	"	Pinus ponderosa	Ponderosa Pine	1.7	1.3	1.3	1.3
2232-A (1281)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.3
2233-A	"	Stipa comata	Needle and Thread				1.7
2234-A (1283)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.0
2235-A (1284)	"	Andropogon scoparius	Little Bluestem				1.1
2236-A (1285)	"	Pinus ponderosa	Ponderosa Pine	1.5	1.3	1.8	1.7
2237-A (1286)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.8
2238-A	"	Artemisia tridentata	Big Sage				2.1
2239-A (1288)	"	Andropogon scoparius	Little Bluestem				1.3

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F^- (by year) 71	72	73	74
2240-A (1289)	E #3	Agropyron spicatum	Bluebunch Wheatgrass				1.7
2241-A (1290)	"	Pinus ponderosa	Ponderosa Pine	1.7	1.4	0.7	0.5
2242-A (1291)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.0
2243-A	"	Artemisia tridentata	Big Sage				2.5
2244-A (1293)	"	Agropyron spicatum	Bluebunch Wheatgrass				0.8
2245-A (1294)	"	Andropogon scoparius	Little Bluestem				0.8
2246-A (1295)	"	Pinus ponderosa	Ponderosa Pine	1.6	1.5	0.7	0.5
2247-A (1296)	"	Juniperus scopulorum	Rocky Mtn. Juniper				4.4
2248-A	"	Yucca glauca	Yucca				3.1
2249-A (1298)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.6
2250-A (1299)	"	Andropogon scoparius	Little Bluestem				0.9
2251-A (1250)	E #4	Pinus ponderosa	Ponderosa Pine	6.4	5.2	3.4	3.2
2252-A (1251)	"	Artemisia tridentata	Big Sage				5.6
2253-A (1252)	"	Chrysothamnus	Rabbitbrush				3.7
2254-A (1253)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.4
2255-A (1254)	"	Andropogon scoparius	Little Bluestem				3.1
2256-A (1255)	"	Pinus ponderosa	Ponderosa Pine	2.9	2.8	2.7	3.0
2257-A (1256)	"	Artemisia tridentata	Big Sage				3.2
2258-A	"	Chrysothamnus	Rabbitbrush				2.9
2259-A (1258)	"	Andropogon scoparius	Little Bluestem				1.6
2260-A (1259)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.6
2261-A (1260)	"	Pinus ponderosa	Ponderosa Pine	2.7	2.6	2.1	2.1
2262-A (1261)	"	Chrysothamnus	Rabbitbrush				3.2
2263-A (1262)	"	Artemisia tridentatum	Big Sage				2.9

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F$^-$ (by year)			
				71	72	73	74
2264-A (1263)	E #4	Agropyron spicatum	Bluebunch Wheatgrass				2.1
2265-A (1264)	"	Andropogon scoparius	Little Bluestem				3.7
2266-A (1265)	"	Pinus ponderosa	Ponderosa Pine	2.1	1.9	2.0	2.9
2267-A	"	Chrysothamnus	Rabbitbrush				3.0
2268-A (1267)	"	Artemisia tridentatum	Big Sage				1.8
2269-A (1268)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.7
2270-A (1269)	"	Andropogon scoparius	Little Bluestem				3.9
2271-A (1270)	"	Pinus ponderosa	Ponderosa Pine	2.1	2.7	1.9	2.0
2272-A	"	Chrysothamnus	Rabbitbrush				2.5
2273-A (1272)	"	Artemisia tridentatum	Big Sage				3.2
2274-A (1273)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.5
2275-A (1274)	"	Andropogon scoparius	Little Bluestem				2.4
2276-A (1175)	NE #4	Andropogon scoparius	Little Bluestem				4.5
2277-A (1176)	"	Artemisia tridentatum	Big Sage				4.4
2278-A (1177)	"	Agropyron spicatum	Bluebunch Wheatgrass				6.8
2279-A (1178)	"	Artemisia cana	Silver Sage				2.0
2280-A (1179)	"	Stipa comata	Needle and Thread				4.5
2281-A (1180)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.0
2282-A (1181)	"	Artemisia tridentatum	Big Sage				3.8
2283-A (1182)	"	Andropogon scoparius	Little Bluestem				1.8
2284-A (1183)	"	Artemisia cana	Silver Sage				2.6
2285-A (1184)	"	Stipa comata	Needle and Thread				2.4
2286-A (1185)	"	Artemisia cana	Silver Sage				2.8
2287-A (1186)	"	Andropogon scoparius	Little Bluestem				2.3

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F^- (by year) 71	72	73	74
2288-A (1187)	NE #4	Artemisia tridentata	Big Sage				4.2
2289-A (1188)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.0
2290-A (1189)	"	Stipa comata	Needle and Thread				3.9
2291-A (1190)	"	" "	" "				2.4
2292-A (1191)	"	Artemisia cana	Silver Sage				6.7
2293-A (1192)	"	Andropogon scoparius	Little Bluestem				2.8
2294-A (1193)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.1
2295-A (1194)	"	Artemisia tridentatum	Big Sage				2.9
2296-A (1195)	"	Artemisia cana	Silver Sage				4.1
2297-A (1196)	"	Andropogon scoparius	Little Bluestem				3.7
2298-A (1197)	"	Stipa comata	Needle and Thread				1.9
2299-A (1198)	:	Juniperus scopulorum	Rocky Mtn. Juniper				3.7
2300-A (1199)	"	Artemisia tridentatum	Big Sage				4.7
2301-A (1300)	N #4	Pinus ponderosa	Ponderosa Pine	3.3	2.1	2.5	1.7
2302-A (1301)	"	Juniperus scopulorum	Rocky Mtn. Juniper				3.8
2303-A (1302)	"	Artemisia cana	Silver Sage				2.0
2304-A (1303)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.9
2305-A (1304)	"	Oryzopsis hymenoides	Indian Rice Grass				2.6
2306-A (1305)	"	Pinus ponderosa	Ponderosa Pine	2.4	2.2	2.1	1.4
2307-A	"	Juniperus scopulorum	Rocky Mtn. Juniper				3.0
2308-A (1307)	"	Artemisia cana	Silver Sage				2.3
2309-A (1308)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.8
2310-A	"	Oryzopsis hymenoides	Indian Rice Grass				2.2
2311-A (1310)	"	Pinus ponderosa	Ponderosa Pine	3.3	2.3	1.7	1.0

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F^- (by year)			
				71	72	73	74
2312-A	N #4	Juniperus scopulorum	Rocky Mtn. Juniper				2.5
2313-A (1312)	"	Artemisia cana	Silver Sage				2.9
2314-A (1313)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.5
2315-A	"	Andropogon scoparius	Little Bluestem				1.8
2316-A (1315)	"	Pinus ponderosa	Ponderosa Pine	1.3	1.3	2.4	1.3
2317-A	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.3
2318-A (1317)	"	Artemisia cana	Silver Sage				2.3
2319-A (1318)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.9
2320-A (1319)	"	Oryzopsis hymenoides	Indian Rice Grass				4.2
2321-A (1320)	"	Pinus ponderosa	Ponderosa Pine	2.3	2.1	3.2	2.3
2322-A (1321)	"	Juniperus scopulorum	Rocky Mtn. Juniper				4.7
2323-A (1322)	"	Artemisia cana	Silver Sage				3.2
2324-A (1323)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.3
2325-A (1324)	"	Oryzopsis hymenoides	Indian Rice Grass				1.2
2326-A (1850)	NE #1	Pinus ponderosa	Ponderosa Pine	4.0	3.6	3.2	2.9
2327-A (1851)	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.3
2328-A (1852)	"	Artemisia cana	Silver Sage				0.4
2329-A (1853)	"	Agropyron spicatum	Bluebunch Wheatgrass				0.2
2330-A (1854)	"	Andropogon scoparius	Little Bluestem				0.1
2331-A (1855)	"	Pinus ponderosa	Ponderosa Pine	1.1	0.4	0.4	0.8
2332-A (1856)	"	Juniperus scopulorum	Rocky Mtn. Juniper				0.1
2333-A (1857)	"	Artemisia cana	Silver Sage				0.6
2334-A (1858)	"	Agropyron spicatum	Bluebunch Wheatgrass				0.9
2335-A (1859)	"	Andropogon scoparius	Little Bluestem				0.8

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F^- (by year)			
				71	72	73	74
2336-A (1860)	NE #1	Pinus ponderosa	Ponderosa Pine	0.8	0.7	0.6	0.6
2337-A (1861)	"	Juniperus scopulorum	Rocky Mtn. Juniper				0.9
2338-A	"						
2339-A (1863)	"	Artemisia cana	Silver Sage				0.8
2340-A (1864)	"	Agropyron spicatum	Bluebunch Wheatgrass				0.6
2341-A (1865)	"	Pinus ponderosa	Ponderosa Pine	1.3	1.1	0.7	0.2
2342-A (1866)	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.2
2343-A (1867)	"	Artemisia cana	Silver Sage				0.7
2344-A (1868)	"	Agropyron spicatum	Bluebunch Wheatgrass				0.3
2345-A (1869)	"	Andropogon scoparius	Little Bluestem				1.3
2346-A (1870)	"	Pinus ponderosa	Ponderosa Pine	2.4	1.7	1.9	0.6
2347-A	"	Juniperus scopulorum	Rocky Mtn. Juniper				0.9
2348-A (1872)	"	Artemisia cana	Silver Sage				1.9
2349-A (1873)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.4
2350-A (1874)	"	Andropogon scoparius	Little Bluestem				1.1
2351-A (1825)	E #1	Pinus ponderosa	Ponderosa Pine	4.7	2.4	1.4	1.9
2352-A (1826)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.7
2353-A	"	Agropyron spicatum	Bluebunch Wheatgrass				2.4
2354-A (1828)	"	Andropogon scoparius	Little Bluestem				2.5
2355-A	"	Calamovilfa longifolia	Sandgrass				1.5
2356-A (1830)	"	Pinus ponderosa	Ponderosa Pine	1.8	2.1	1.7	1.4
2357-A (1831)	"	Juniperus scopulorum	Rocky Mtn. Juniper				4.0
2358-A (1832)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.3
2359-A (1833)	"	Andropogon scoparius	Little Bluestem				1.8

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F^- (by year) 71	72	73	74
2360-A (1834)	E #1	Calamovilfa longifolia	Sandgrass				1.0
2361-A (1835)	"	Pinus ponderosa	Ponderosa Pine	2.5	1.4	1.9	1.2
2362-A	"	Artemisia cana	Silver Sage				3.1
2363-A (1837)	"	Agropyron spicatum	Bluebunch Wheatgrass				1.8
2364-A (1838)	"	Andropogon scoparius	Little Bluestem				1.6
2365-A (1839)	"	Calamovilfa longifolia	Sandgrass				1.0
2366-A (1840)	"	Pinus ponderosa	Ponderosa Pine	1.6	1.5	2.1	1.6
2367-A	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.8
2368-A (1842)	"	Agropyron spicatum	Bluebunch Wheatgrass				0.8
2369-A (1843)	"	Andropogon scoparius	Little Bluestem				2.0
2370-A (1844)	"	Aristida longiseta	Red Three Awn				1.1
2371-A (1845)	"	Pinus ponderosa	Ponderosa Pine	2.7	3.2	2.2	1.4
2372-A (1846)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.1
2373-A (1847)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.2
2374-A (1848)	"	Andropogon scoparius	Little Bluestem				3.7
2375-A (1849)	"	Calamovilfa longifolia	Sandgrass				1.5
2376-A (1225)	E #5	Pinus ponderosa	Ponderosa Pine	9.9	3.5	3.0	1.6
2377-A (1226)	"	Juniperus scopulorum	Rocky Mtn. Juniper				4.5
2378-A (1227)	"	Andropogon scoparius	Little Bluestem				1.5
2379-A (1228)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.7
2380-A (1229)	"	Aristida longiseta	Red Three Awn				1.4
2381-A (1230)	"	Pinus ponderosa	Ponderosa Pine	3.6	2.6	3.2	1.4
2382-A (1231)	"	Artemisia cana	Silver Sage				2.5
2383-A (1232)	"	Juniperus scopulorum	Rocky Mtn. Juniper				2.0

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm F^- (by year)			
				71	72	73	74
2384-A (1233)	E #5	Andropogon scoparius	Little Bluestem				2.7
2385-A (1234)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.3
2386-A (1235)	"	Pinus ponderosa	Ponderosa Pine	2.5	2.6	2.2	1.4
2387-A (1236)	"	Juniperus scopulorum	Rocky Mtn. Juniper				3.2
2388-A (1237)	"	Andropogon scoparius	Little Bluestem				1.4
2389-A (1238)	"	Agropyron spicatum	Bluebunch Wheatgrass				2.2
2390-A	"	Aristida longiseta	Red Three Awn				2.9
2391-A (1240)	"	Pinus ponderosa	Ponderosa Pine	2.2	3.5	2.4	1.4
2392-A (1241)	"	Juniperus scopulorum	Rocky Mtn. Juniper				3.1
2393-A	"	Calamovilfa longifolia	Sandgrass				1.3
2394-A (1243)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.8
2395-A (1244)	"	Andropogon scoparius	Little Bluestem				2.0
2396-A (1245)	"	Pinus ponderosa	Ponderosa Pine	2.3	1.5	2.5	1.4
2397-A (1246)	"	Juniperus scopulorum	Rocky Mtn. Juniper				1.5
2398-A	"	Artemisia cana	Silver Sage				2.9
2399-A (1248)	"	Agropyron spicatum	Bluebunch Wheatgrass				3.2
2400-A (1249)	"	Andropogon scoparius	Little Bluestem				1.8

APPENDIX B - PART II

COLSTRIP SAMPLES - VEGETATION - SULFUR
FALL, 1974

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year) 71	72	73	74
2001-A (1495)	SE #1	Pinus ponderosa	Ponderosa Pine	800	700	700	700
2002-A (1496)	"	Juniperous scopulorum	Rocky Mtn. Juniper				800
2003-A (1497)	"	Andropogon scoparius	Little Bluestem				300
2004-A (1498)	"	Agropyron spicatum	Bluebunch Wheatgrass				700
2005-A (1499)	"	Calamovilfa longifolia	Sandgrass				500
2006-A (1490)	"	Pinus ponderosa	Ponderosa Pine	600	650	800	700
2007-A (1491)	"	Juniperous scopulorum	Rocky Mtn. Juniper				700
2008-A (1492)	"	Andropogon scoparius	Little Bluestem				400
2009-A	"						
2010-A (1494)	"	Calamovilfa longifolia	Sandgrass				600
2011-A (1485)	"	Pinus ponderosa	Ponderosa Pine	700	700	700	700
2012-A (1486)	"	Juniperous scopulorum	Rocky Mtn. Juniper				700
2013-A (1487)	"	Agropyron spicatum	Bluebunch Wheatgrass				600
2014-A (1488)	"	Andropogon scoparius	Little Bluestem				400
2015-A	"	Calamovilfa longifolia	Sandgrass				500
2016-A (1480)	"	Pinus ponderosa	Ponderosa Pine	700	700	700	700
2017-A (1481)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2018-A (1482)	"	Calamovilfa longifolia	Sandgrass				600
2019-A (1483)	"	Andropogon scoparius	Little Bluestem				400
2020-A (1484)	"	Agropyron spicatum	Bluebunch Wheatgrass				700
2021-A (1475)	"	Pinus ponderosa	Ponderosa Pine	700	700	700	700
2022-A (1476)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year)			
				71	72	73	74
2023-A (1477)	SE #1	Artemisia cana	Silver Sage				2200/2200*
2024-A (1478)	"	Andropogon scoparius	Little Bluestem				400
2025-A (1479)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2076-A (1200)	W #4	Pinus ponderosa	Ponderosa Pine	800	600	700	1000
2077-A (1201)	"	Rhus trilobata	Skunkbrush				700
2078-A (1202)	"	Artemisia cana	Silver Sage				1100
2079-A (1203)	"	Andropogon scoparius	Little Bluestem				400
2080-A (1204)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2081-A (1205)	"	Pinus ponderosa	Ponderosa Pine	500	500	500	500
2082-A (1206)	"	Artemisia cana	Silver Sage				2600
2083-A (1207)	"	Rhus trilobata	Skunkbrush				500
2084-A (1208)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2085-A (1209)	"	Andropogon scoparius	Little Bluestem				300
2086-A (1210)	"	Pinus ponderosa	Ponderosa Pine	800	800	900	800
2087-A (1211)	"	Artemesia cana	Silver Sage				2600
2088-A (1212)	"	Rhus trilobata	Skunkbrush				800
2089-A (1213)	"	Agropyron spicatum	Bluebunch Wheatgrass				600
2090-A (1214)	"	Andropogon scoparius	Little Bluestem				600
2091-A (1215)	"	Pinus ponderosa	Ponderosa Pine	600	700	700	700
2092-A (1216)	"	Rhus trilobata	Skunkbrush				500/600*
2093-A (1217)	"	Artemisia cana	Silver Sage				2600/2600*
2094-A (1218)	"	Agropyron spicatum	Bluebunch Wheatgrass				800/800*
2095-A (1219)	"	Andropogon scoparius	Little Bluestem				400/300*
2096-A (1220)	"	Pinus ponderosa	Ponderosa Pine	700	600	600	800

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year) 71	72	73	74
2097-A (1221)	W #4	Rhus trilobata	Skunkbrush				700
2098-A (1222)	"	Artemisia cana	Silver Sage				2100
2099-A (1223)	"	Agropyron spicatum	Bluebunch Wheatgrass				300
2100-A (1224)	"	Andropogon scoparius	Little Bluestem				300
2101-A (1750)	W #3	Pinus ponderosa	Ponderosa Pine	700/ 800	700	700	700
2102-A (1751)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2103-A (1752)	"	Artemisia cana	Silver Sage				2900/3000
2104-A	"	Agropyron spicatum	Bluebunch Wheatgrass				700
2105-A	"	Yucca glauca	Yucca				800
2106-A (1755)	"	Pinus ponderosa	Ponderosa Pine	900	700	900	700
2107-A (1756)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700/700
2108-A	"	Artemisia cana	Silver Sage				2500
2109-A	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2110-A	"	Aristida longiseta	Red Three Awn				600
2111-A (1760)	"	Pinus ponderosa	Ponderosa Pine	600	500	700	600
2112-A (1761)	"	Juniperus scopulorum	Rocky Mtn. Juniper				800
2113-A (1762)	"	Artemisia cana	Silver Sage				2000
2114-A (1763)	"	Agropyron spicatum	Bluebunch Wheatgrass				700/600
2115-A	"	Andropogon scoparius	Little Bluestem				400
2116-A (1765)	"	Pinus ponderosa	Ponderosa Pine	400	700	600	600
2117-A (1766)	"	Juniperus scopulorum	Rocky Mtn. Juniper				400
2118-A (1767)	"	Yucca glauca	Yucca				800
2119-A (1768)	"	Agropogon spicatum	Bluebunch Wheatgrass				500
2120-A	"	Andropogon scoparius	Little Bluestem				400

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year) 71	72	73	74
2121-A (1770)	W #3	Pinus ponderosa	Ponderosa Pine	600	700	600	600
2122-A (1771)	"	Juniperus scopulorum	Rocky Mtn. Juniper				900
2123-A (1772)	"	Yucca glauca	Yucca				700
2124-A (1773)	"	Agropyron spicatum	Bluebunch Wheatgrass				700
2125-A (1774)	"	" "	" "				300
2126-A (1350)	NW #4	Pinus ponderosa	Ponderosa Pine	1000/ 900	600/ 700	900	900
2127-A (1351)	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2128-A (1352)	"	Rhus trilobata	Skunkbrush				700
2129-A (1353)	"	Agropyron spicatum	Bluebunch Wheatgrass				600
2130-A (1354)	"	Andropogon scoparius	Little Bluestem				400
2131-A (1355)	"	Pinus ponderosa	Ponderosa Pine	500	800/ 700	800	800
2132-A (1356)	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2133-A (1357)	"	Rhus trilobata	Skunkbrush				1100
2134-A (1358)	"	Agropyron spicatum	Bluebunch Wheatgrass				800
2135-A (1359)	"	Andropogon scoparius	Little Bluestem				400
2136-A (1360)	"	Pinus ponderosa	Ponderosa Pine	600	800	700	700
2137-A (1361)	"	Rhus trilobata	Skunkbrush				800/700
2138-A (1362)	"	Artemisia cana	Silver Sage				2200
2139-A (1363)	"	Agropyron spicatum	Bluebunch Wheatgrass				600
2140-A (1364)	"	Andropogon scoparius	Little Bluestem				400
2141-A (1365)	"	Pinus ponderosa	Ponderosa Pine	700	800	900	800
2142-A (1366)	"	Rhus trilobata	Skunkbrush				800
2143-A (1367)	"	Juniperus scopulorum	Rocky Mtn. Juniper				
2144-A (1368)	"	Agropyron spicatum	Bluebunch Wheatgrass				700/600

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year) 71	72	73	74
2145-A (1369)	NW #4	Andropogon scoparius	Little Bluestem				200
2146-A (1370)	"	Pinus ponderosa	Ponderosa Pine	500	800	700	700
2147-A (1371)	"	Rhus trilobata	Skunkbrush				800
2148-A (1372)	"	Artemisia cana	Silver Sage				2700
2149-A (1373)	"	Andropogon scoparius	Little Bluestem				800
2150-A (1374)	"	Calamovilfa longifolia	Sandgrass				600
2151-A (1775)	NW #3	Pinus ponderosa	Ponderosa Pine	900	700	700	500
2152-A (1776)	"	Juniperus scopulorum	Rocky Mtn. Juniper				800
2153-A (1777)	"	Artemisia tridentata	Big Sage				1500
2154-A (1778)	"	Agropyron spicatum	Bluebunch Wheatgrass				550
2155-A (1779)	"						
2156-A (1780)	"	Pinus ponderosa	Ponderosa Pine	650/ 750	800	900	800
2157-A (1781)	"	Artemisia tridentata	Big Sage				1100
2158-A (1782)	"	Artemisia cana	Silver Sage				2500
2159-A (1783)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2160-A (1784)	"	Aristida longiseta	Red Three Awn				850
2161-A (1785)	"	Pinus ponderosa	Ponderosa Pine	800	850	550	800
2162-A (1786)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2163-A (1787)	"	Artemisia cana	Silver Sage				2100
2164-A (1788)	"	Agropyron spicatum	Bluebunch Wheatgrass				600
2165-A	"	Andropogon scoparius	Little Bluestem				400
2166-A (1790)	"	Pinus ponderosa	Ponderosa Pine	750	500	650	600
2167-A (1791)	"	Juniperus scopulorum	Rocky Mtn. Juniper				600/550
2168-A (1792)	"	Artemisia cana	Silver Sage				2400

COLSTRIP SAMPLES (Continued)

		Species	Species	Ppm S (by year)			
F#	Site	Scientific Name	Common Name	71	72	73	74
2169-A (1793)	NW #3	Agropyron spicatum	Bluebunch Wheatgrass				400
2170-A (1794)	"	Aristida longiseta	Red Three Awn				500/400
2171-A (1795)	"	Pinus ponderosa	Ponderosa Pine	600	600/550	600	600
2172-A (1796)	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2173-A (1797)	"	Artemisia cana	Silver Sage				2200
2174-A (1798)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2175-A (1799)	"	Calamovilfa longifolia	Sandgrass				400
2176-A (1575)	NE #3	Pinus ponderosa	Ponderosa Pine	450	550	500	600
2177-A (1576)	"	Juniperus scopulorum	Rocky Mtn. Juniper				550
2178-A (1577)	"	Artemisia cana	Silver Sage				2800
2179-A (1578)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2180-A (1579)	"	Andropogon scoparius	Little Bluestem				200/200
2181-A (1580)	"	Pinus ponderosa	Ponderosa Pine	550	550	700	700
2182-A (1581)	"	Juniperus scopulorum	Rocky Mtn. Juniper				500
2183-A (1582)	"	Artemisia cana	Silver Sage				2750
2184-A (1583)	"	Agropyron spicatum	Bluebunch Wheatgrass				200/200
2185-A (1584)	"	Andropogon scoparius	Little Bluestem				200/200
2186-A (1585)	"	Pinus ponderosa	Ponderosa Pine	400	400	400	500
2187-A (1586)	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2188-A (1587)	"	Chrysothamnus nauseosus	Rubber Rabbitbrush				900
2189-A (1588)	"	Agropyron spicatum	Bluebunch Wheatgrass				300
2190-A (1589)	"	Andropogon scoparius	Little Bluestem				400
2191-A (1590)	"	Pinus ponderosa	Ponderosa Pine	600	600	550	400
2192-A (1591)	"	Juniperus scopulorum	Rocky Mtn. Juniper				400

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year)			
				71	72	73	74
2193-A (1592)	NE #3	Artemisia tridentata	Big Sage				1100
2194-A (1593)	"	Agropyron spicatum	Bluebunch Wheatgrass				200/300
2195-A (1594)	"	Andropogon scoparius	Little Bluestem				200/200
2196-A (1595)	"	Pinus ponderosa	Ponderosa Pine	400	400	600	600
2197-A (1596)	"	Juniperus scopulorum	Rocky Mtn. Juniper				500
2198-A (1597)	"	Artemisia tridentata	Big Sage				900
2199-A (1598)	"	Agropyron spicatum	Bluebunch Wheatgrass				550
2200-A (1599)	"	Andropogon scoparius	Little Bluestem				300
2201-A (1050)	SE #3	Pinus ponderosa	Ponderosa Pine	650	650	550	700
2202-A	"	Yucca glauca	Yucca				1400
2203-A	"	Andropogon scoparius	Little Bluestem				400
2204-A (1053)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2205-A (1054)	"	Stipa comata	Needle and Thread				400
2206-A (1055)	"	Pinus ponderosa	Ponderosa Pine	500	500	700	700
2207-A	"	Artemisia cana	Silver Sage				2700
2208-A (1057)	"	Chrysothamnus viscidiflorus	Green Rabbitbrush				2800
2209-A (1058)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2210-A (1059)	"	Stipa comata	Needle and Thread				400
2211-A (1060)	"	Pinus ponderosa	Ponderosa Pine	750	600	700	500
2212-A	"	Andropogon scoparius	Little Bluestem				300
2213-A (1062)	"	Chrysothamnus viscidiflorus	Green Rabbitbrush				2100
2214-A (1063)	"	Agropyron spicatum	Bluebunch Wheatgrass				650
2215-A (1064)	"	Stipa comata	Needle and Thread				500

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year) 71	72	73	74
2216-A (1065)	SE #3	Pinus ponderosa	Ponderosa Pine	500	700	700	600
2217	"	Andropogon scoparius	Little Bluestem				300/350
2218-A (1067)	"	Chrysothamnus viscidiflorus	Green Rabbitbrush				1000/1000
2219-A (1068)	"	Agropyron spicatum	Bluebunch Wheatgrass				600
2220-A (1069)	"	Stipa comata	Needle and Thread				500
2221-A (1070)	"	Pinus ponderosa	Ponderosa Pine	600	700/ 700	750/ 800	650
2222-A	"	Chrysothamnus viscidiflorus	Green Rabbitbrush				1850
2223-A	"	Andropogon scoparius	Little Bluestem				300
2224-A (1073)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2225-A (1074)	"	Stipa comata	Needle and Thread				500
2226-A (1275)	E #3	Pinus ponderosa	Ponderosa Pine	600	750	800	700
2227-A (1276)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2228-A	"	Stipa comata	Needle and Thread				400
2229-A (1278)	"	Agropyron spicatum	Bluebunch Wheatgrass				450
2230-A (1279)	"	Andropogon scoparius	Little Bluestem				300
2231-A (1280)	"	Pinus ponderosa	Ponderosa Pine	700	750	800	700
2232-A (1281)	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2233-A	"	Stipa comata	Needle and Thread				500
2234-A (1283)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2235-A (1284)	"	Andropogon scoparius	Little Bluestem				300
2236-A (1285)	"	Pinus ponderosa	Ponderosa Pine	700	750	750	750
2237-A (1286)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2238-A	"	Artemisia tridentata	Big Sage				1300
2239-A (1288)	"	Andropogon scoparius	Little Bluestem				400

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year)			
				71	72	73	74
2240-A (1289)	E #3	Agropyron spicatum	Bluebunch Wheatgrass				400
2241-A (1290)	"	Pinus ponderosa	Ponderosa Pine	700	950	1100/ 950	800
2242-A (1291)	"	Juniperus scopulorum	Rocky Mtn. Juniper				650
2243-A	"	Artemisia tridentata	Big Sage				1400
2244-A (1293)	"	Agropryon spicatum	Bluebunch Wheatgrass				400
2245-A (1294)	"	Andropogon scoparius	Little Bluestem				300
2246-A (1295)	"	Pinus ponderosa	Ponderosa Pine	700	700	900	700
2247-A (1296)	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2248-A	"	Yucca glauca	Yucca				1000/950
2249-A (1298)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2250-A (1299)	"	Andropogon scoparius	Little Bluestem				400
2251-A (1250)	E #4	Pinus ponderosa	Ponderosa Pine	600	900	900	650
2252-A (1251)	"	Artemisia tridentata	Big Sage				700
2253-A (1252)	"	Chrysothamnus	Rabbitbrush				1800
2254-A (1253)	"	Agropyron spicatum	Bluebunch Wheatgrass				200
2255-A (1254)	"	Andropogon scoparius	Little Bluestem				500
2256-A (1255)	"	Pinus ponderosa	Ponderosa Pine	600	600	600	600
2257-A (1256)	"	Artemisia tridentata	Big Sage				900
2258-A	"	Chrosothamnus	Rabbitbrush				1600
2259-A (1258)	"	Andropogon scoparius	Little Bluestem				700
2260-A (1259)	"	Agropyron spicatum	Bluebunch Wheatgrass				300
2261-A (1260)	"	Pinus ponderosa	Ponderosa Pine	600	700	600	600
2262-A (1261)	"	Chrysothamnus	Rabbitbrush				600
2263-A (1262)	"	Artemisia tridentata	Big Sage				1400

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year) 71	72	73	74
2264-A (1263)	E #4	Agropyron spicatum	Bluebunch Wheatgrass				600
2265-A (1264)	"	Andropogon scoparius	Little Bluestem				200
2266-A (1265)	"	Pinus ponderosa	Ponderosa Pine	600	600/ 550	700	800
2267-A	"	Chrysothamnus	Rabbitbrush				3300/300
2268-A (1267)	"	Artemisia tridentata	Big Sage				1570
2269-A (1268)	"	Agropyron spicatum	Bluebunch Wheatgrass				300
2270-A (1269)	"	Andropogon scoparius	Little Bluestem				300
2271-A (1270)	"	Pinus ponderosa	Ponderosa Pine	700	600	700	600
2272-A	"	Chrysothamnus	Rabbitbrush				500
2273-A (1272)	"	Artemisia tridentata	Big Sage				900
2274-A (1273)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2275-A (1274)	"	Andropogon scoparius	Little Bluestem				300
2276-A (1175)	NE #4	Andropogon scoparius	Little Bluestem				200
2277-A (1176)	"	Artemisia tridentata	Big Sage				1200
2278-A (1177)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2279-A (1178)	"	Artemisia cana	Silver Sage				3500/3300
2280-A (1179)	"	Stipa comata	Needle and Thread				350
2281-A (1180)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2282-A (1181)	"	Artemisia tridentata	Big Sage				1100
2283-A (1182)	"	Andropogon scoparius	Little Bluestem				200
2284-A (1183)	"	Artemisia cana	Silver Sage				1750
2285-A (1184)	"	Stipa comata	Needle and Thread				250
2286-A (1185)	"	Artemisia cana	Silver Sage				2300
2287-A (1186)	"	Andropogon scoparius	Little Bluestem				250

COLSTRIP SAMPLES (Continued)

		Species	Species	Ppm S (by year)			
F#	Site	Scientific Name	Common Name	71	72	73	74
2288-A (1187)	NE #4	Artemisia tridentata	Big Sage				1400
2289-A (1188)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2290-A (1189)	"	Stipa comata	Needle and Thread				300
2291-A (1190)	"	" "	" "				600
2292-A (1191)	"	Artemisia cana	Silver Sage				3000
2293-A (1192)	"	Andropogon scoparius	Little Bluestem				400
2294-A (1193)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2295-A (1194)	"	Artemisia tridentata	Big Sage				1300
2296-A (1195)	"	Artemisia cana	Silver Sage				2300
2297-A (1196)	"	Andropogon scoparius	Little Bluestem				300
2298-A (1197)	"	Stipa comata	Needle and Thread				600
2299-A (1198)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2300-A (1199)	"	Artemisia tridentata	Big Sage				1200
2301-A (1300)	N #4	Pinus ponderosa	Ponderosa Pine	700	700	600	700
2302-A (1301)	"	Juniperus scopulorum	Rocky Mtn. Juniper				750
2303-A (1302)	"	Artemisia cana	Silver Sage				2100
2304-A (1303)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2305-A (1304)	"	Oryzopsis hymenoides	Indian Rice Grass				700
2306-A (1305)	"	Pinus ponderosa	Ponderosa Pine	700	700	700	600
2307-A	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2308-A (1307)	"	Artemisia cana	Silver Sage				2600
2309-A (1308)	"	Agropyron spicatum	Bluebunch Wheatgras				500
2310-A	"	Oryzopsis hymenoides	Indian Rice Grass				700/600
2311-A (1310)	"	Pinus ponderosa	Ponderosa Pine	700	700	700	600

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year)			
				71	72	73	74
2312-A	N #4	Juniperus scopulorum	Rocky Mtn. Juniper				800
2113-A (1312)	"	Artemisia cana	Silver Sage				2400
2314-A (1313)	"	Agropyron spicatum	Bluebunch Wheatgrass				600
2315-A	"	Andropogon scoparius	Little Bluestem				300
2316-A (1315)	"	Pinus ponderosa	Ponderosa Pine	600	700	700	700
2317-A	"	Juniperus scopulorum	Rocky Mtn. Juniper				400
2318-A (1317)	"	Artemisia cana	Silver Sage				1800
2319-A (1318)	"	Agropyron spicatum	Bluebunch Wheatgrass				700
2320-A (1319)	"	Oryzopsis hymenoides	Indian Rice Grass				500
2321-A (1320)	"	Pinus ponderosa	Ponderosa Pine	500	600	700	600
2322-A (1321)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2323-A (1322)	"	Artemisia cana	Silver Sage				2300
2324-A (1323)	"	Agropryon spicatum	Bluebunch Wheatgrass				400
2325-A (1324)	"	Oryzopsis hymenoides	Indian Rice Grass				800
2326-A (1850)	NE #1	Pinus ponderosa	Ponderosa Pine	600	600	700	700
2327-A (1851)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2328-A (1852)	"	Artemisia cana	Silver Sage				2000
2329-A (1853)	"	Agropyron spicatum	Bluebunch Wheatgrass				600
2330-A (1854)	"	Andropogon scoparius	Little Bluestem				300
2331-A (1855)	"	Pinus ponderosa	Ponderosa Pine	700	700	600	600
2332-A (1856)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2333-A (1857)	"	Artemisia cana	Silver Sage				2300
2334-A (1858)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2335-A (1859)	"	Andropogon scoparius	Little Bluestem				300

COLSTRIP SAMPLES (Continued)

		Species	Species	Ppm S (by year)			
F#	Site	Scientific Name	Common Name	71	72	73	74
2336-A (1860)	NE #1	Pinus ponderosa	Ponderosa Pine	700	700	800	600
2337-A (1861)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2338-A							
2339-A (1863)	"	Artemisia cana	Silver Sage				2200
2340-A (1864)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2341-A (1865)	"	Pinus ponderosa	Ponderosa Pine	600	800	800	700
2342-A (1866)	"	Juniperus scopulorum	Rocky Mtn. Juniper				800
2343-A (1867)	"	Artemisia cana	Silver Sage				2800
2344-A (1868)	"	Agropyron spicatum	Bluebunch Wheatgrass				600
2345-A (1869)	"	Andropogon scoparius	Little Bluestem				500
2346-A (1870)	"	Pinus ponderosa	Ponderosa Pine	750	750	900	700
2347-A	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2348-A (1872)	"	Artemisia cana	Silver Sage				3400
2349-A (1873)	"	Agropyron spicatum	Bluebunch Wheatgrass				600
2350-A (1874)	"	Andropogon scoparius	Little Bluestem				400
2351-A (1825)	E #1	Pinus ponderosa	Ponderosa Pine	700	700	800	650
2352-A (1826)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2353-A	"	Agropyron spicatum	Bluebunch Wheatgrass				700
2354-A (1828)	"	Andropogon scoparius	Little Bluestem				300
2355-A	"	Calamovilfa longifolia	Sandgrass				600
2356-A (1830)	"	Pinus ponderosa	Ponderosa Pine	800	700	800	800
2357-A (1831)	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2358-A (1832)	"	Agropryon spicatum	Bluebunch Wheatgrass				500
2359-A (1833)	"	Andropogon scoparius	Little Bluestem				500

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year) 71	72	73	74
2360-A (1834)	E #1	Calomovilfa longifolia	Sandgrass				700
2361-A (1835)	"	Pinus ponderosa	Ponderosa Pine	600	700	700	600
2362-A	"	Artemisia cana	Silver Sage				1900
2363-A (1837)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2364-A (1838)	"	Andropogon scoparius	Little Bluestem				400
2365-A (1839)	"	Calamovilfa longifolia	Sandgrass				600
2366-A (1840)	"	Pinus ponderosa	Ponderosa Pine	700	700	800	600
2367-A	"	Juniperus scopulorum	Rocky Mtn. Juniper				700
2368-A (1842)	"	Agropyron spicatum	Bluebunch Wheatgrass				550
2369-A (1843)	"	Andropogon scoparius	Little Bluestem				500
2370-A (1844)	"	Aristida longiseta	Red Three Awn				700
2371-A (1845)	"	Pinus ponderosa	Ponderosa Pine	600	600	800	700
2372-A (1846)	"	Juniperus scopulorum	Rocky Mtn. Juniper				400
2373-A (1847)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2374-A (1848)	"	Andropogon scoparius	Little Bluestem				400
2375-A (1849)	"	Calamovilfa longifolia	Sandgrass				900
2376-A (1225)	E #5	Pinus ponderosa	Ponderosa Pine	800	800	700	700
2377-A (1226)	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2378-A (1227)		Andropogon scoparius	Little Bluestem				300
2379-A (1228)	"	Agropyron spicatum	Bluebunch Wheatgrass				400
2380-A (1229)	"	Aristida longiseta	Red Three Awn				600
2381-A (1230)	"	Pinus ponderosa	Ponderosa Pine	600	700	700	800
1382-A (1231)	"	Artemisia cana	Silver Sage				1900
2383-A (1232)	"	Juniperus scopulorum	Rocky Mtn. Juniper				700

COLSTRIP SAMPLES (Continued)

F#	Site	Species Scientific Name	Species Common Name	Ppm S (by year) 71	72	73	74
2384-A (1233)	E #5	Andropogon scoparius	Little Bluestem				200
2385-A (1234)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2386-A (1235)	"	Pinus ponderosa	Ponderosa Pine	600	600	600	600
2387-A (1236)	"	Juniperus scopulorum	Rocky Mtn. Juniper				500
2388-A (1237)	"	Andropogon scoparius	Little Bluestem				200
2389-A (1238)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2390-A	"	Aristida longiseta	Red Three Awn				700
2391-A (1240)	"	Pinus ponderosa	Ponderosa Pine	700	800	900	900
2392-A (1241)	"	Juniperus scopulorum	Rocky Mtn. Juniper				500
2393-A	"	Calamovilfa longifolia	Sandgrass				700
2394-A (1243)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2395-A (1244)	"	Andropogon scoparius	Little Bluestem				400
2396-A (1245)	"	Pinus ponderosa	Ponderosa Pine	500	600	800	600
2397-A (1246)	"	Juniperus scopulorum	Rocky Mtn. Juniper				600
2398-A	"	Artemisia cana	Silver Sage				2600
2399-A (1248)	"	Agropyron spicatum	Bluebunch Wheatgrass				500
2400-A (1249)	"	Andropogon scoparius	Little Bluestem				400

APPENDIX C
AIR POLLUTION - INSECT POLLINATION
PERTINENT LITERATURE

by

JERRY J. BROMENSHENK

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APPENDIX D

BIOLOGICAL IMPACT OF AIR POLLUTION ON INSECTS

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Insect populations, which comprise 75 percent of all animal species, respond significantly to air contaminants. Unfortunately, our understanding of insect-pollutant relationships is restricted primarily to studies of a few benficial and destructive species such as honeybees and pests of forests. The extant reports consist of historical and geographical surveys of insects near industrial sources, a few laboratory fumigation experiments, and disparate biochemical and genetic studies.

Insect populations often increase or decrease in numbers in response to pollution stress. In areas of Pennsylvania subjected to elevated levels of sulfur dioxide, significant increases in the number of aphids (Aphidae) and decreases in the numbers of social bees (Apidae) and several parasitic wasp (Hymenoptera) families were recorded--the increase of aphids may have been de to a SO_2 induced parasite imbalance (15). A highly significant relationship between an increase in tree damage by two species of needle miners, Ocnerostoma strobivorum (Zeller) and Zellaria haimbachi (Busck) and ambient and foliar concentrations of fluoride in lodgepole pine, Pinus contorta v. latifolia Engelm. was observed near an aluminum reduction facility at Columbia Falls, Montana. The data indicated that fluoride disposed the pines to insect injury (2). A negative correlation between the size of ground beetle populations and the rate of fallout of sodium sulphate existed near a Kraft mill in Canada; the change in insect numbers may have been due to SO_2^{2-} or to other particulates (13). Most ground beetles are predatory, and like their beetle allies, the ladybugs, attack noxious insects.

Some contaminants accumulate in the tissues of insects. Four major groups of insects--pollinators, predators, foliage feeders, and cambial feeders--collected near an aluminum smelter (Montana) and analyzed for fluoride content contained 58.0 to 585.0 ppm fluoride (dry weight), 6.1 to 170.0 ppm, 21.3 to 255.0 ppm, and 8.5 to 52.5 ppm, respectively. Control insects had 3.5 to 16.5 ppm of fluoride. "The relatively high fluoride levels in the 100 percent predatory insects indicate fluorides are either accumulated by respiration or are passed along the food chain (5). Other reports indicate that fluorides (see Figure 1), arsenites, trace elements and fractions of particulates may accumulate in insect tissue (1, 3, 5, 6, 7, 11, 17, 18, 21, 23, 26, 28). Tissue concentrations of contaminants (and presumably their effects) vary with different insects, climate, geography, and pollution factors. Insect species, activity, age, development, feeding habits; weather patterns, wind, precipitation; contaminant species, composition and form--all influence uptake. But, contaminants do not necessarily have to be accumulated to affect insect populations either directly by toxicosis or indirectly through chain reactions among dependent organisms.

A fallacy of many field studies of air pollution and insects has been the use of data that correlates changes in insect populations, such as mortalities, with ambient air concentrations or tissue concentrations of a single contaminant to indict the contaminant as the "cause" of mortality and event to estimate toxicity. Harm by air contaminants is demonstrated by such surveys, but the data are usually insufficient to identify a specific causal agent. Air pollution does not consist of single contaminants, but rather consists of complexes of gases and particulates that may be physically and chemically transformed during atmospheric transport. The effects of air pollution results from interactions of many contaminants. Assessments of specific, individual pollutants is largely a matter of "practical" simplification of the problem and a lack of understanding of the interactions of contaminants

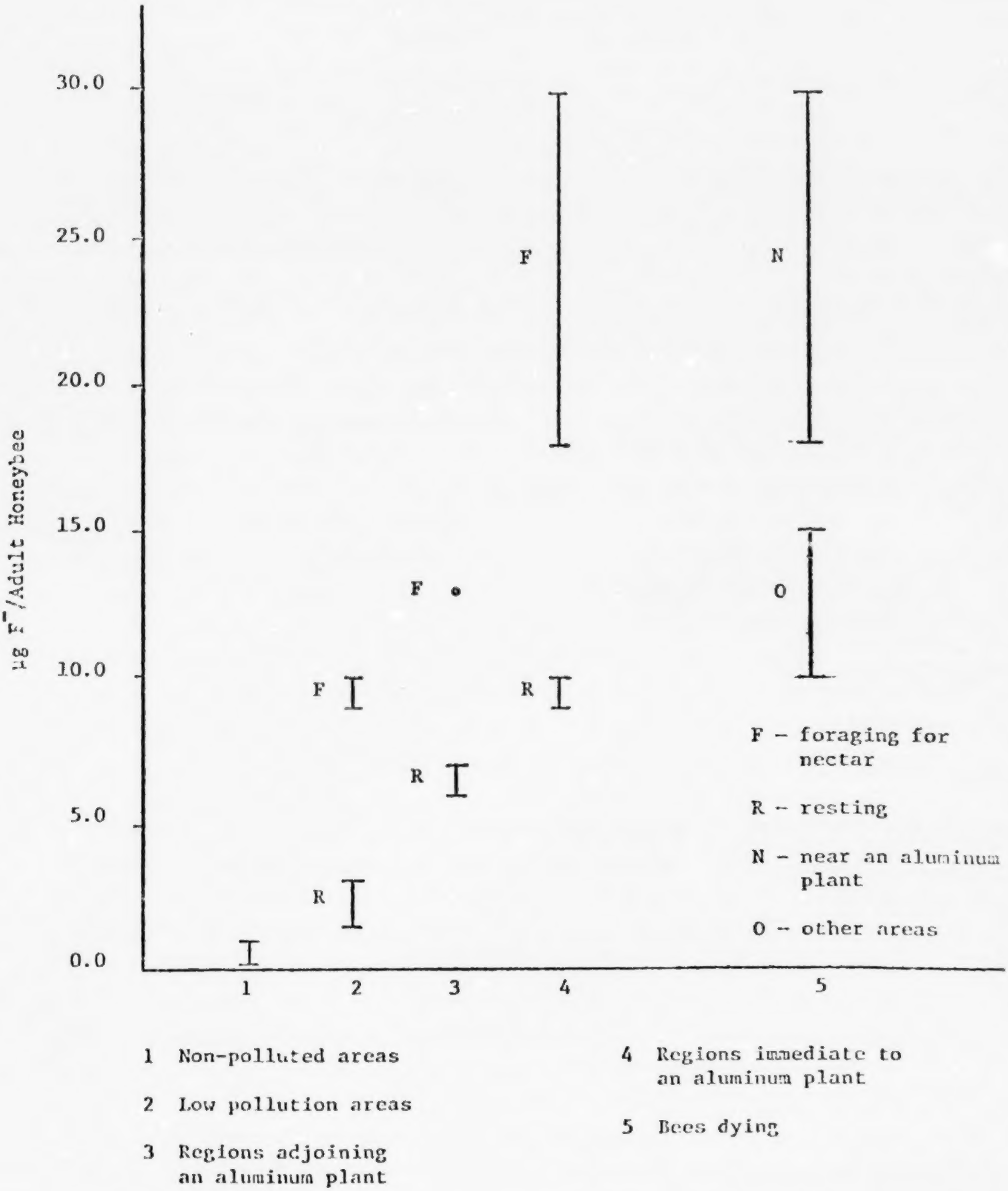
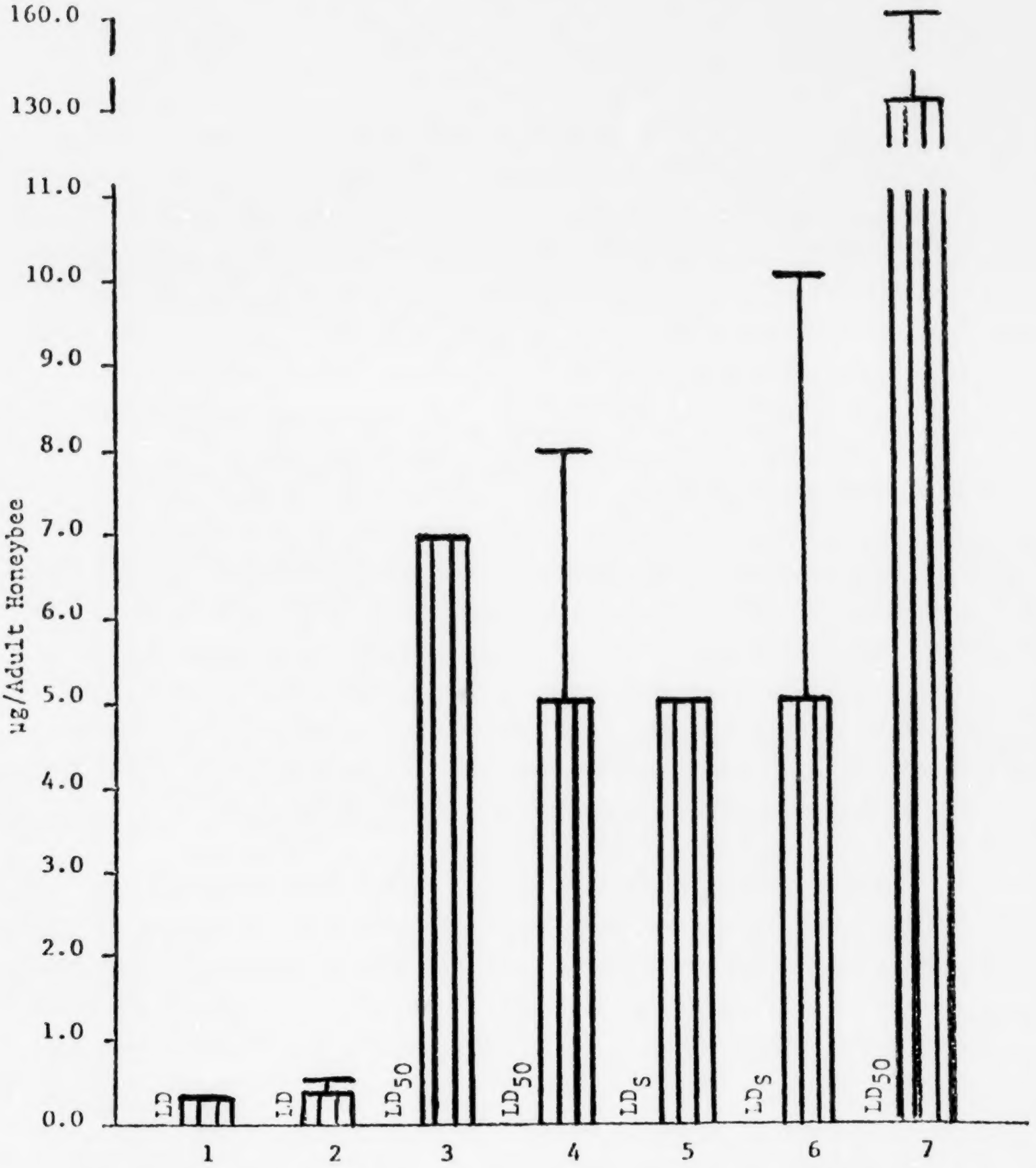


Fig. 1. Accumulation of fluorides in tissues of adult honeybees near industrial areas as reported by Guilhon (11).

and other environmental factors. The total impact of pollutants and environmental stresstors is not simply additive. Not only contaminant emitting sources, but other sources of evironmental insults must be examined. For insect studies, a frequent confounding stressor is pesticides.

Toxicosis is usually an obvious manifestation of pollution injury. Episodic, acute exposures to pollutants may result in marked displays of insect population response such as serious losses of honeybees due to arsenic or pesticide poisonings. Figure 2 shows some lethal doses of contaminants to honeybees. But, episodic exposure may not be as important to a biological system as chronic, low level exposures to air contaminants over periods of years. Low level of pollutants or low toxicities do not imply low hazard to insects. Chemicals such as arsenic and the organophosphate insecticide, carbaryl, may have little effect on foraging bees, but are accumulated in the brood--a situation analagous to control of ants in which case on seeks a slow acting, low level toxic to increase effectiveness (Dr. Roy V. Barker, letter dated March 14, 1975, USDA Bee Research Laboratory, Tucson, Arizona).

Sublethal as well as lethal effects of contaminants are important. Physiological, biochemical, genetic and behavioral consequences of air pollution are superficially understood. Some information is available for honeybees (Hymenoptera), less is available for flies and midges (Diptera), and practically nothing is known for other insects. The toxicology of a few contaminants as insecticides (such as arsenic and carbon disulfide) has been examined although lethal dose determinations predominate, and the biochemical processes are sketchily understood for most compounds. For example, sulphuryl flouride in eggs of desert locusts and yellow mealworms "appears" to act as an inhibitor of several metabolic processes and may be nonspecific in respect to sites of attack (22). Genetic studies of pollution effects have been restricted primarily



1 Arsenic trioxide (17)

2 Sodium arsenate (26)

3 Potassium cyanide (21)

4 Sodium fluoride (18)
Ammonium fluoride
Ammonium bifluoride
Hydrofluoric acid

5 Sodium fluoride (11)

6 Calcium fluoride (11)

7 Sodium aluminum (18)
fluoride

Fig. 2. Comparative determinations of the lethal doses of pollutants to honeybees. Numbers in parentheses refer to authors.

to Drosophila species (fruit flies). Hydrogen fluoride at 1.3 to 2.9 ppm reduced hatchability and fecundity of D. melanogaster, presumably as a result of genetic damata (9). Chromosone disjunction has been induced in Drosophilia by feeding 0.25 mg mercury (methyl mercury hydroxide/kg substrate) (23). Fumigation treatments of D. melanogaster for 6 to 12 hours of hydrogen fluoride (hydroflouric acid at 2.5 percent concentrations) produced a trend toward higher frequencies of lethal and sublethal chromosomes (drastics) with increased treatment duration (20). Pollutant induced behavior modifications occur. Anaesthesia with carbon dioxide or nitrous oxide induced permanent changes in the behavior of honeybees--pollen collecting was reduced or suspended, while brood rearing and wax secreting were eliminated by young bees because these bees began foraging at an earlier age (24). Sublethal doses of parathion prevented honeybees from communicating to other bees by dancing the direction of a food source (27). Similar doses of parathion changed the singing patterns of crickets (Acheta domesticus L.) and resulted in prevention of successful copulation by cricket males, while sublethal doses of Dieldren and Sevin resulted in complete cessation of singing for 3-6 hours (31).

Although the relationships between insect populations and air contaminants are obscure, the indirect effects of air pollution on insects such as vegetation responses to pollutants and subsequent respones by associated obligative and facultative insects are practically unknown, except for a few studies of insect infestations on pollutant stressed forests (2, 3, 4, 29). The observed increases of insect pests on pollution stressed vegetation may be due to: (1) increased susceptibility of plants because of weakened physiological condition (2) reduction or elimination of parasites and predators of the insect pests; (3) movements of insect populations to or from these areas, or (4) combinations of these factors and presumably other factors yet to be identified. Air pollution may affect only a few components of an ecosystem, yet these may initiate chain reactions among dependent organisms. Adverse impacts of air contaminants on beneficial insects (pollinators) have been frequently reported, but it is conceivable in some instances that pollinators might increase in numbers--air pollution stress can increase flowering of some plants, and pollinators such as the social bees reflect changes in nutritional supplies through their brood rearing. However, many pollutants have direct adverse effects on bees and as such exert a limiting influence on population size.

Pollinators may be one of the insect systems most sensitive to air pollutant stress. Pollination (entomophily) depends primarily on bees (Hymentoptera). Flies and midges (Diptera) are second to bees in visiting thrips (Thysanoptera), beetles (Coleptera), and other orders of insects contribute in various degrees. Bees are the best pollinators, being morphologically and behaviorally specialized for pollent transport. The hairy bodies of solitary and social bees are well adapted for pollen collection. Unlike insects that collect pollen for their immediate needs, bees collect pollen not only for their own needs, but also to provision the nest and brood. This necessitates extensive foraging and efficient collection and transport of nectar and pollen. The branched hairs on the bodies of many bees are well suited to the collection and transport of particulate contaminants. Obviously, the repeated and often lengthy foraging journeys of bees increase the likelihood of these insects encountering a pollution source. There is probably more information about air pollution and insect response for honeybees than for any other species of insects, but one still cannot generalize even about the response of honeybees or of other species of bees to particular pollutant complexes. For example, susceptibility of four species of bees to field weathered insecticides occurred as follows: alfalfa leafcutter bees > alkali bees > honeybees > bumblebees. Susceptibility appeared to increase as the surface: volume ratio increased (bumblebees are as much as nine times the mass of leafcutter bees), although factors such as hairiness and behavior probably contributed (16).

Throughout the U.S. many areas already are experiencing lack of native pollinators. S. E. McGregor says that approximately one-third of the total U.S. diet is derived, directly or indirectly from insect pollinated crops. He quotes (14), "....there has been an increasing accumulation of data to indicate that seed fields of insect pollinated crops can be lower than they need to be, not because of climate, soil, or cultural practices, but simply because the population of certain insects is low." Mr. McGregor concludes that there is a need for 5 to 20 times the number of manageable colonies of bees available--an additional 2.5 to 10 millon colonies (19). California growers now important honeybees from as far away as North Dakata to satisfy pollination needs. Yet honeybees cannot replace native pollinators to meet the pollination requirements of many plants. Approximately 37 species of native insects are capable of pollinating onions, but honeybees are not as effective. (Telephone conversation, March 15, 1975, Dr. Frank D. Parker, USDA Bee Biology and Systematics Laboratory, Logan Utah. Pesticide poisoning is responsible for much of the current shortage of pollinators, yet air pollution is rapidly increasing as a contributing factor. In telephone conversation (March, 1975) with the major research groups involved with pollination and pollution research, investigators repeatedly reported observations of an absence of pollinators, especially bees, in industrial and urban areas, although hard data is often lacking to support these observations. But commercial beekeepers often do not or cannot keep honeybees downwind from industrial developments such as smelters and fossil fuel-burning power plants. It is reasonable to expect adverse effects of air pollution on other pollinators.

Obviously, studies should be initiated very soon to clarify the relationships of insects and air pollution. Again, in our telephone interviews, we could not find any research projects concerned with insects and pollution in the U.S. except for those current in progress under the auspices of the Environmental Protection Agency, Corvallis, Oregon, in the Fort Union Basin area of Southeast Montana.

The coal-fired power plant development in Southeast Montana affords a unique opportunity to investigate some of the consequences of air contaminants on insect systems. Both forest and grassland areas occur in the vicinity of the power plant complex. A number of insect systems are available for study. Most importantly is the opportunity to conduct baseline studies before the power plants begin operation in an area that is relatively pollution free at the present time and the opportunity to work with a multi-institution, multi-disciplinary research effort. Ongoing studies in the Fort Union area include examinations of plant communities, biomass, fungi, vertebrates, meteorology, lichens, reclamation, soils, hydrology and socio-economics. The grasslands biome project (Colorado State University) includes investigations of the invertebrate consumer components of the grassland ecosystems. Included are identification and quantification of above and belowground macro-and micro-invertebrates.

The Environmental Studies Laboratory, University of Montana, under the Direction of Dr. C. C. Gordon was awarded a grant by the Environmental Protection Agency on August 1, 1974 to conduct studies on vegetation, fungi and insect components of the Fort Union area. Although a number of insect systems are available for study and should be examined, it would be futile to attempt to look at all of the insects. Specifically, we selected dominant, indigenous insect-plant populations which have a diversified, but understandable realtionship. We considered feasibilitv biological importance and economic impact. Certain insect populations are sensitive indicators of pollution stress, and these appeared to have the greatest potential for supplying useful and understandable information. Consequently, the insect work has been concentrated on two groups: pollinators and infestations on Ponderosa pines by pest insects. Both showed specific respones to air contamination in previous studies, appear to be very sensitive pollution indicators, are economically important to the region, and are manageable for research purposes.

The Fort Union development provides an excellent opportunity for field experimentation. Unfortunately, since the shakedown operations of the power plant complex will begin this spring (1975), baseline data should already have been obtained. In some instances it has. Studies of insect population response should be oriented towards field investigations. Laboratory studies have value, but laboratory results do not necessarily correspond to events in the much more complex environment of an ecosystem. For example exposure to 5,000 rads of gamma or neutron irradiation reduced by 21 percent the life span of worker honeybees housed in laboratory cages. Yet, when an entire colony was irradiated with 5,000 rads and returned to the field, the bees perished (10). Most researchers are cognizant of the problems associated with conducting field experiments in complex environments. Oversimplification of the field environment as a "control" measure, in essence, establishes a quasi-laboratory condition. Cultivation of non-cultivated plants, irrigation of plants normally receiving only natural rainfall, elimination of insect pests, transplantation of plants to areas in which they would not normally occur, destructive sampling--procedures such as these simply testing but may invalidate extrapolation of results to the real world. Field controls ideally consist of natural sites in which confounding factors are identified and monitored, not eliminated. Hopefully, this can be accomplished in the Fort Union Basin.

There can be no doubt that air contaminants affect insect populations, although the exact processes are not understood. It is reasonable to expect biologic and economic costs of air pollution stress. We need to know at what level of pollution the economic and biologic consequences are important as well as to identify the effects. We must assess the actual significance of insect populations, benficial and destructive, to the Southeast Montana ecosystems. Ultimately, biologic impact is expressed in terms of economic impact. Who pays for destructive insect infestations to forests? What is the cost of replacing or supporting pollination study (5). The mean sulfur content was 4392 ppm, SD=286. Sulfur occurs as a natural portion of animal tissue and there appears to be some question as to whether or not it is accumulated, although exposure to SO_2 at 8.2 ppm for three weeks increased sulfate in honeybee haemolymph by a significant amount (12). Pesticide analyses being conducted in cooperation with this project by Dr. Ronald Thomas, EPA, Biological Investigations Laboratory, Beltsville, Maryland, revealed the presence of low level residues of chlorinated hydrocarbons in bees from four sites. Some 700-800 colonies of bees were killed in the Fort Union area in 1974, presumably as a result of pesticide poisonings. Pesticide poisonings have occurred previously in this area, and therefore, it is essential to consider this pollutant source with that of the air contaminants emitted by the power plants. We shall continue these chemical analyses over the next 2-3 years, after the power plants have become operative. We intend to perform analyses for trace elements as well as to utilize AchE determinations as an index of sulfur interaction.

Our approach to the bees will be as inclusive as possible. We shall monitor behavioral responses through the use of observation beehives and a ferrous-metal capture-recapture system. The latter (8) consists of small metal tags that are affixed to bees and collected at monitoring points by magnets. This method is particularly useful for monitoring foraging activities. We shall monitor biopathways of pollutant uptake through the use of pollen and dead bee collectors and conduct fumigation experiments at the EPA zonal air pollution delivery system in Southeastern Montana and in the laboratory. Finally, we shall examine indications of physiological condition such as brood rearing, colony activity, and colony size.

Our work with the pest infestations on Ponderosa pine is concerned with: (1) estimates of the endemic insects and pollution damage being sustained by the pines, (2) comparisons over the next few years to determine if insect damage has appreciably increased, and (3) if this increase correlates to a significant degree with foliar and precipitation content of pollutants such as fluorides and sulfurs. The condition of the pines is rated via vigor rating which takes into account factors such as needle retention, needle necrosis, and other physiological symptoms of pollution stress. Our data from 1974 indicates that insect damage in the area was usually very slight, with the exception of fairly severe loss of seed production because of cone boring insects such as *Conophthorus* beetles and *Laspeyresia* and *Dioryctria* moths. This type of damage affects seed production, but does not appreciably injure the tree itself. Several studies have shown significant correlations in the relationships of pest damage and foliar and ambient air concentrations in the relationships of pest damage and foliar and ambient air concentrations of air contaminants. However, these studies have always relied on data obtained after the source of the contaminants have been in operation for extended periods of time. Therefore, whereas the level of pollution and the size of the insect populations may correlate, the total impact or extent of the increase over that of an "undisturbed" situation is unknown.

Obviously, other insect systems should be investigated in Southeast Montana. One of the more significant systems is that of the western harvester ant. Another consists of the grasshopper populations which periodically have been severe pests of the rangelands. The "Applicant's Environmental Analysis" (30) recognized the following economically important insects and arachnids present in the impacted area: Rocky Mountain ticks, mosquitos, fleas, and deer flies as vectors of human disease; pine beetles, larch casebearers, spruce budworms, and mountain pine beetles as forest pests. The applicants made no mention of agriculturally important insects such as pollinators and those species predacious or parasitic on invertebrate pests.

Commercial honeybees are important to the economics of the Colstrip, Montana, area. Approximately 3,000 colonies of honeybees are maintained i the Fort Union Basin. These colonies provide bee products such as honey and wax, are valuable pollinators of alfalfa seed crops, and at least 1,000 colonies are transported annually to California (October through April) and rented for pollination of crops. At a very conservative estimate, the honeybee industry comprises a $240,000 to $300,000 enterprise (at a value of $80-100 per colony for bees and products). Floyd Moeller, research leader of the North Central States Bee Laboratory, Madison, Wisconsin, estimates the actual economic value of honeybees as pollinators at 20 times their value as honeymakers. This means that the honeybees in Southeast Montana may be worth $3-4.5 million as pollinators of rangelands and agricultural lands in Montana and an additional $500,000 to one million dollars as pollinators of California crops. (Data based on marketable honey yields from 1,200 colonies in the Fort Union Basin, confidential report.) In addition to honeybees, native bees are plentiful in the Colstrip area as evidenced by my observations in August-October of 1974. Currently, native bees may be capable of satisfying the pollination needs of most of the vegetation of the Fort Union area. However, evidence from insecticide problems indicate that the native bees, especially the physically smaller species, may be much more susceptible to pollutant toxicosis than honeybees.

The manageability and numbers of honeybees in the study area make them an excellent tool. We obtained samples of adult honeybees from thirteen apiaries in October of 1974 for chemical analyses. We have completed fluoride and sulfur analyses, have obtained partial results from pesticide analyses, and have a bank of fresh frozen and dried material for additional chemical analyses. The baseline levels of contaminants in this area appear to be low: fluoride averaged 7.4 ppm dry weight, SD=3.1, in adult bees (unpublished data), which compares favorably with the 10.0 ppm found in control bees for the Columbia Falls systems by importing the cost of replacing or supporting pollination systems by importing insects such as now occurs in California? What are the consequences of a lack of pollinators to plant diversity and abundance on rangelands and eventual impact on the cattle industry? What is the impact of increased foliage feeders such as aphids on agricultural crops? These are but a few of the questions that need to be answered. Unfortunately, we will not answer any or all of these questions without intensive long-term studies. Evaluations of pollution impact must be tested by gathering baseline information under "pollution free" conditions. Areas in which this can be done are becoming increasingly difficult to find. The Fort Union Basin afforded one such opportunity, although advance notice was not sufficient to allow long-term baseline studies. Obviously, we cannot accurately predict the location or intensity of new pollution sources. Therefore, we need to find undisturbed areas and conduct baseline studies while such areas are available. S. E. McGregor, in a recent synopsis of the significance and research needs of insect pollination, stated: "Many....crop varieties grown today, have been tested under insecticide-free conditions to determine the actual value of the pollinators unhampered by damaging pesticides" (19). Considering the worldwide distribution of pesticide use, one must ask if a totally insecticide-free area exists. The same may soon be true for pollution-free areas.

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APPENDIX E.

DISSECTION WORKSHEET FOR WHOLE CARCASS ANALYSIS

Species: ______________________________ Spec. No. ______________

Capture Site ____________________________________ Sex ___ Age ___

Capture Wt ____________________ gm. Date ____________________

Disposition ____

Field or Exper History ______________________________________

Post-capture Body Weights: Wt _____ gm. Date ____________________;

Wt _____ gm. Date ________________; Wt _____ gm. Date ______________;

Date of Dissection ____________; Age __________; Body Wt ___________ gm.;

History Immediately Prior to Death ______________________________

Lesions, Abnormalities & Ectoparasites ____________________________

____

____

Type of Molt___________; Plum. Aspect____________; Wing_________ mm;

Bill________ mm; Tarsomet________ mm; Body Molt____________________;

Wing molt____

Growing Remiges ____

____

Outer 1°___________ mm; Penult 1°___________ mm; Tail molt_____________;

Decks__________ mm; Outer Rectrices____________ mm; Tail____________mm;

Cloacal Protub: Length________________ mm; Diameter________________mm;

Shape of Vent________________; Bursal Orifice (±) ____________________.

Remarks____

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____

____

____

Vent. Apter. (d,v,o) __________________; Wet Wt __________________ mg.;

Dry Wt __________ mg; Integument Dry Wt. __________ mg;

PECTORALIS: Wet Wt. ______ mg; Dry Wt. _____ mg; DW Calorie Sample _____ mg;

DW Cal. _______; Fat Free Wt. ________ mg; FF Calorie Sample __________ mg;

FF Cal. _______; N Sample _______ mg; N _________ g/kg; Fat Class __________;

FURCULAR FAT SAMPLE: Wet Wt. _____ mg; Dry Wt. _____ mg;

Calorie Sample _____ mg; Calories _______; WET CROP & CONTENTS ________ mg;

Wet Crop _____ mg; CROP CONTENTS: Dry Cal Sample __________ mg;

Calories ______; Dry N Sample ______ mg; N ________ g/kg;

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Thymus (Cr. lat. diam.) __________ mm, ______________________________

____

Gonadal Sex__________; Wet Ovary_________ mg; Cicatrix_______________;

Pre-ov Foll. (mm)____;

Post-ov Foll. (mm)____;

Wet Oviduct_________ mg; Ova_________ mm; Ova____________________ mg;

Left Testis_________ mm; Right Testis_________ mm;

Wet Testes, Left ________ mg; Right_________ mg; Combined_________ mg;

Wet Heart_________ mg; Dry Heart_________ mg; Wet Bursa____________ mg;

Wet Adrenals_________ mg; Wet Kidney__________ mg; Wet Spleen_______ mg;

LIVER: Wet _________ mg; Dry________ mg; DW Cal. Sample___________ mg;

DW Cal.__________; Fat Free Wt_________; FF Cal. Sample____________ mg;

FF Cal.__________; N Sample______________ mg; N_________________ g/kg;

Wet Gizzard, Full___________mg; Empty___________mg; Intestinal Contents

Dry______ mg; N____ g/kg; Trachea______; Lungs, Wet _____mg; Dry____mg;

CARCASS: Dry Wt. __________________ mg; DW Cal. Sample____________ mg;

DW Cal. ______________________; Fat Free Wt. ____________________ mg;

FF Cal. Sample_________ mg; FF Cal.__________; Dry N Sample ________ mg;

N_________ g/kg; Dry Ash Sample____________ mg; Ash_______________ mg;

Internal Parasites____

____

Other Information: ______________________________________

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TISSUE	ADDITIONAL PROCESSING
Carcass sample	dry; for chem. assay (e.g. pesticide scan)

Code: DW = dry weight

N = nitrogen

FF = fat free

foll = follicles

cal = calorie